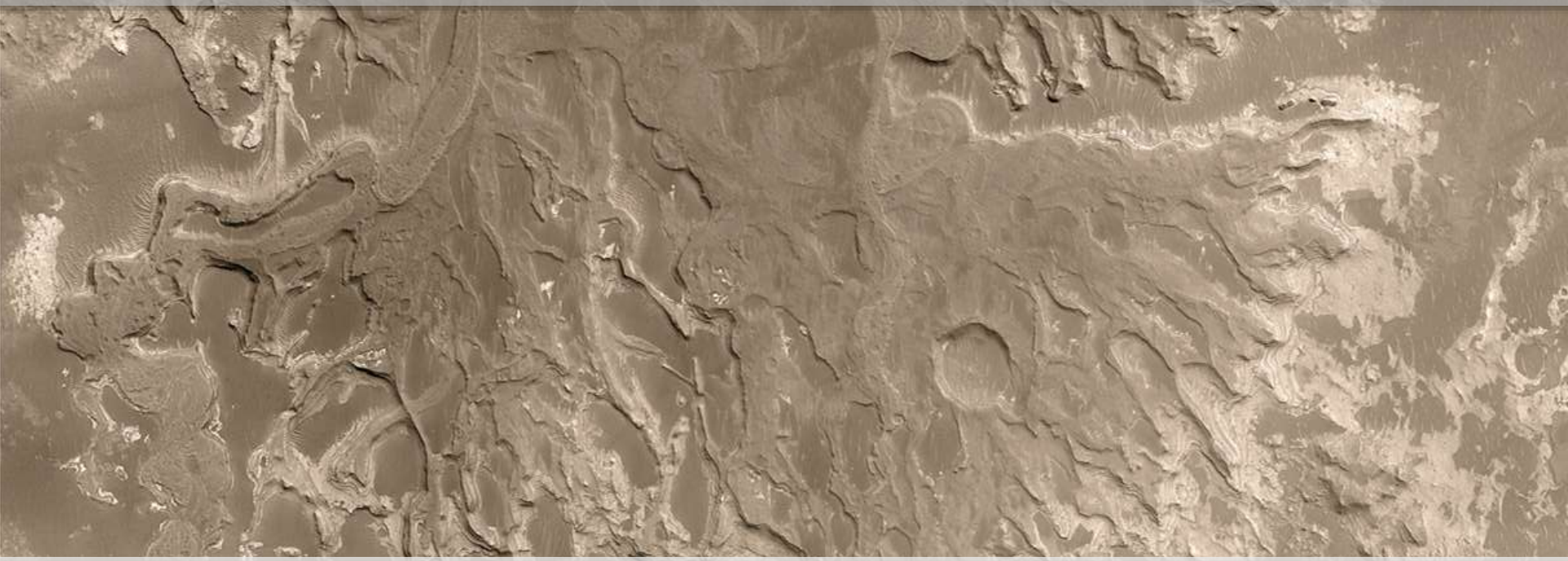
Eberwalde Crater:
Habitability and Geologic Diversity



Melissa Rice, Ross Irwin, Nick Warner, Sanjeev Gupta, Jacob Adler

2nd Mars 2020 Landing Site Workshop, 4 August 2015

ULM System Downstream

N: Nirgal Vallis

U: Uzboi Vallis

L: Ladon Valles

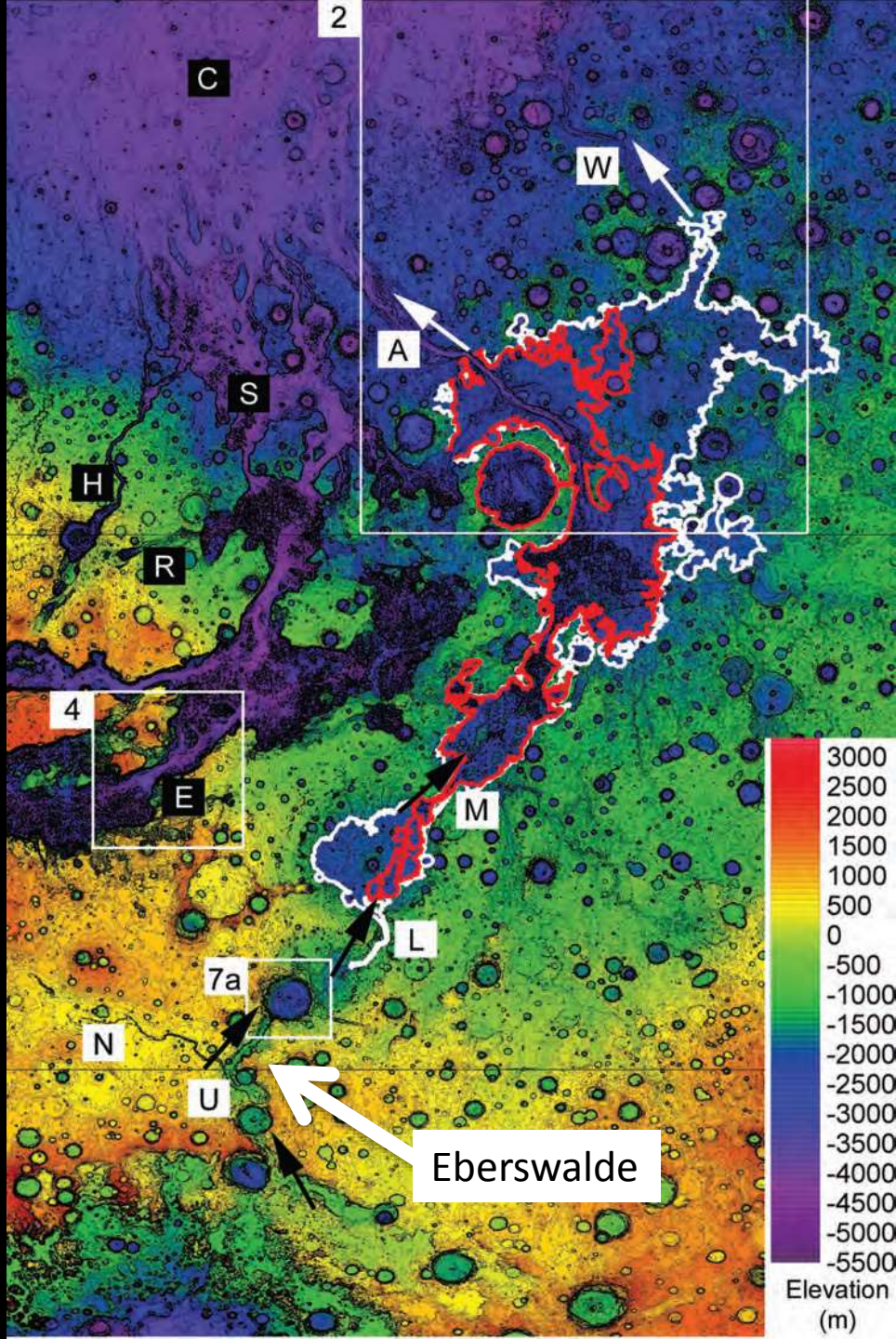
M: Morava Valles

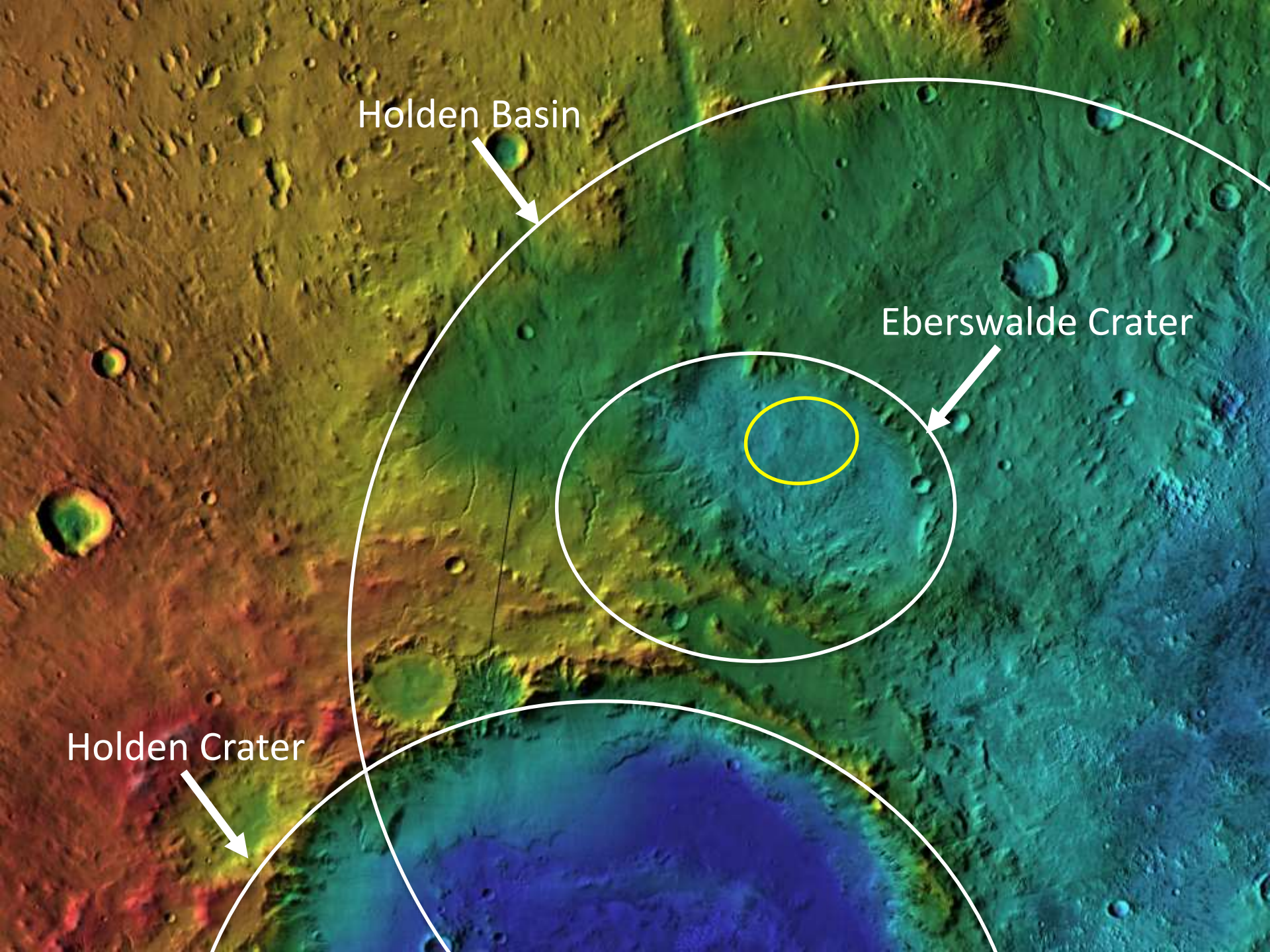
A: Ares Vallis

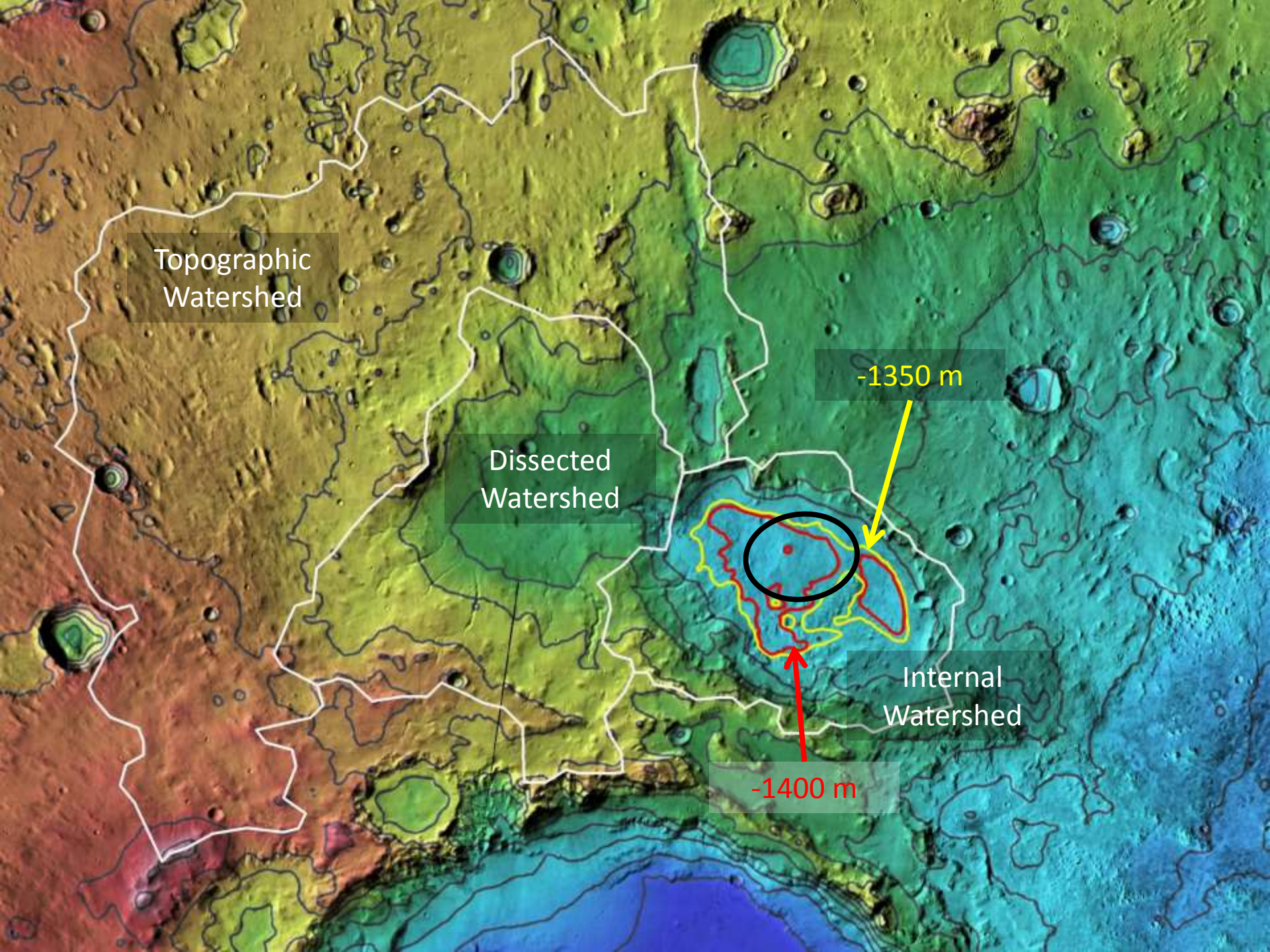
W: Mawrth Vallis

White: -1880 m. Red: -2000 m

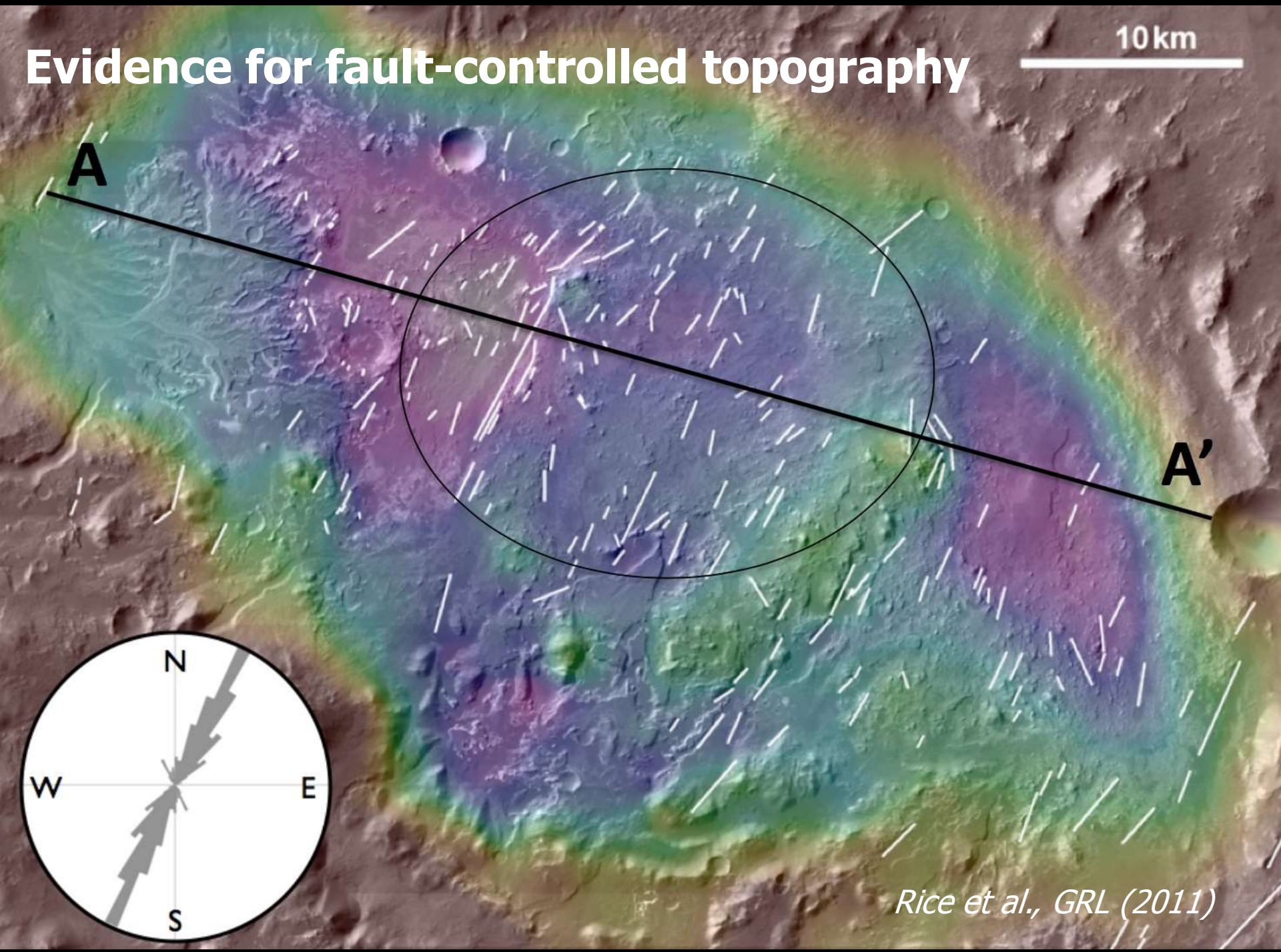
Irwin and Grant (2009) in Burr et al. (2009) eds., *Megaflooding on Earth and Mars*




Holden Basin
Eberswalde Crater
Holden Crater

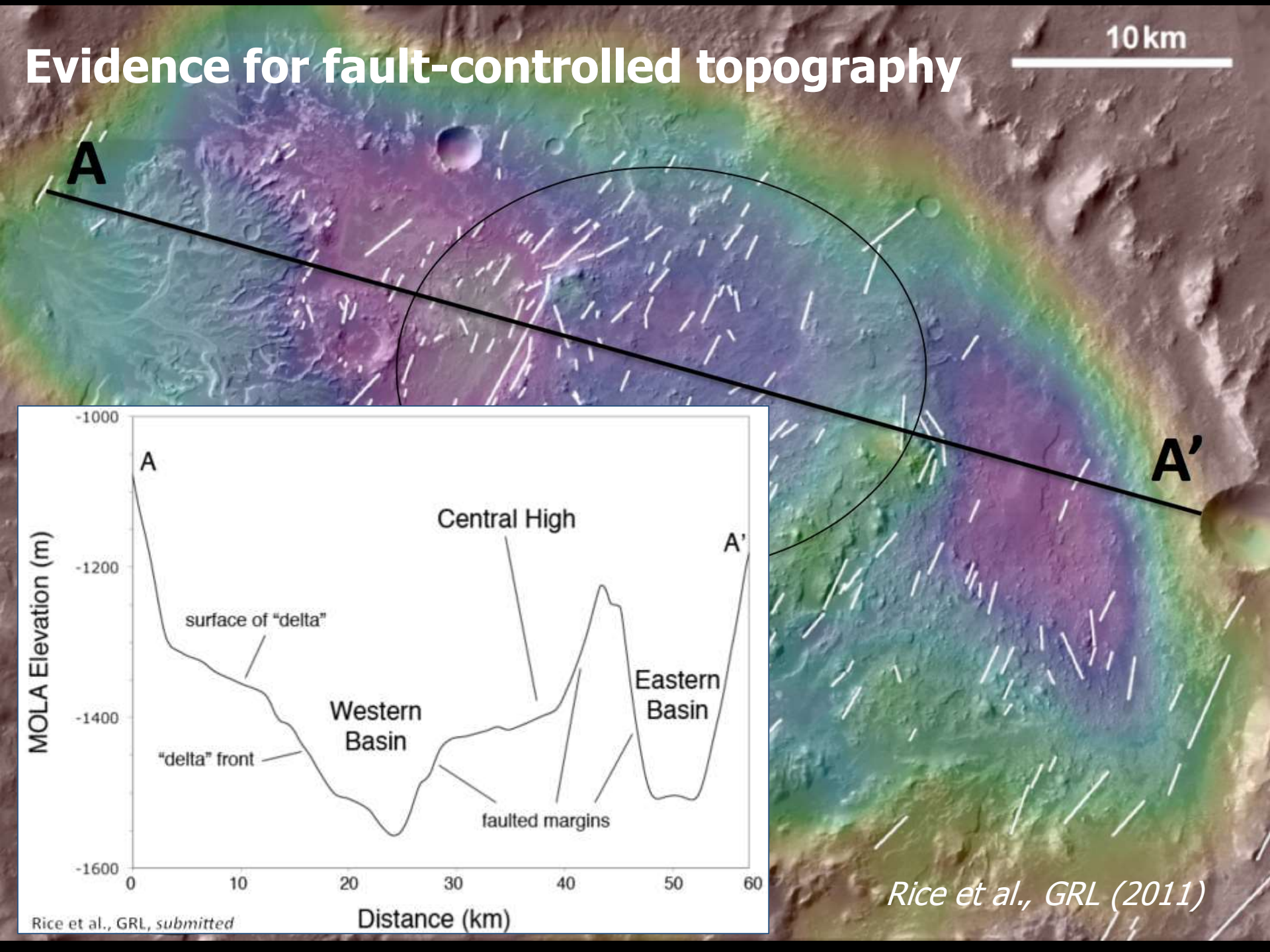

Topographic Watershed
Dissected Watershed
-1350 m
Internal Watershed
-1400 m

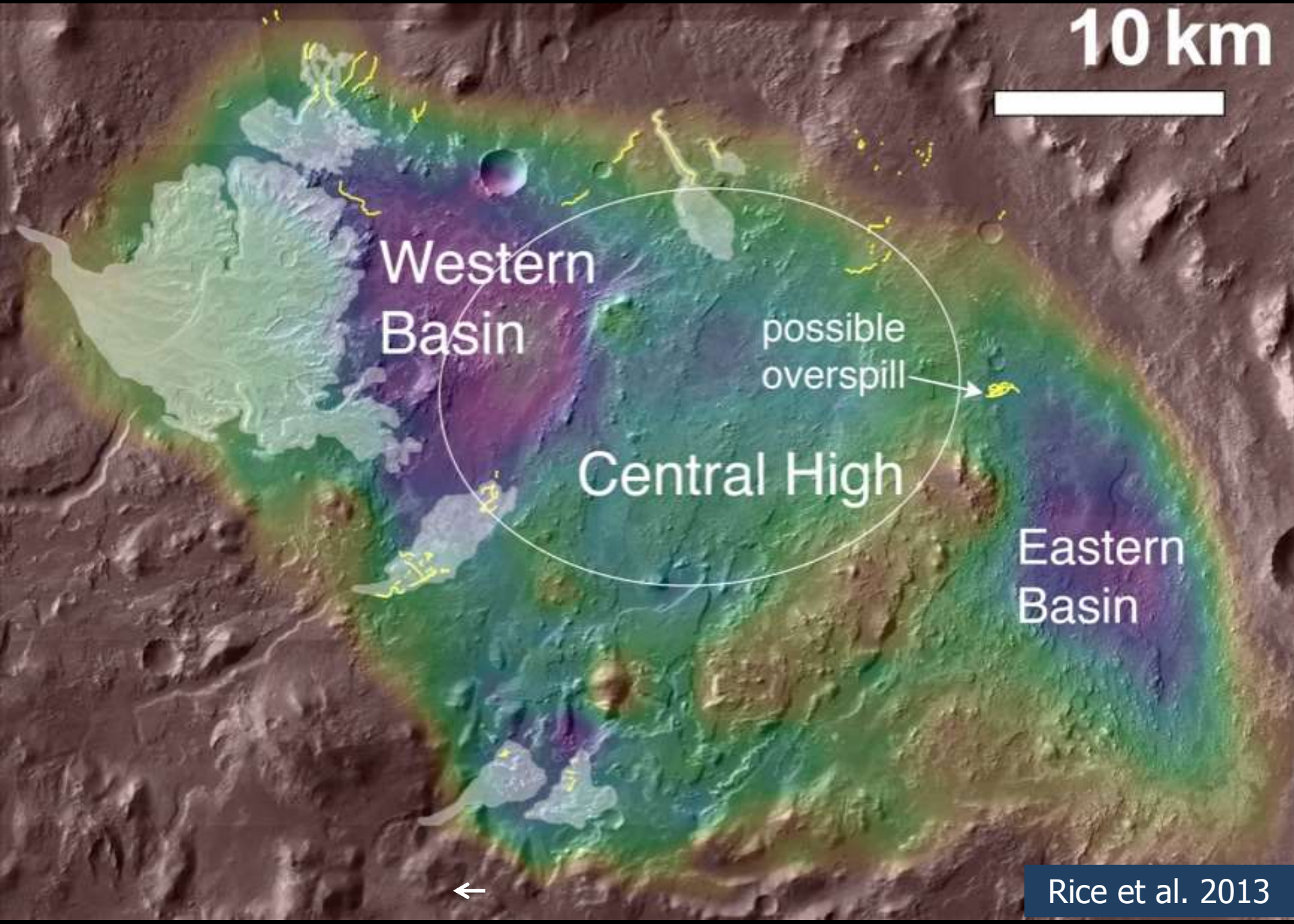
Evidence for fault-controlled topography



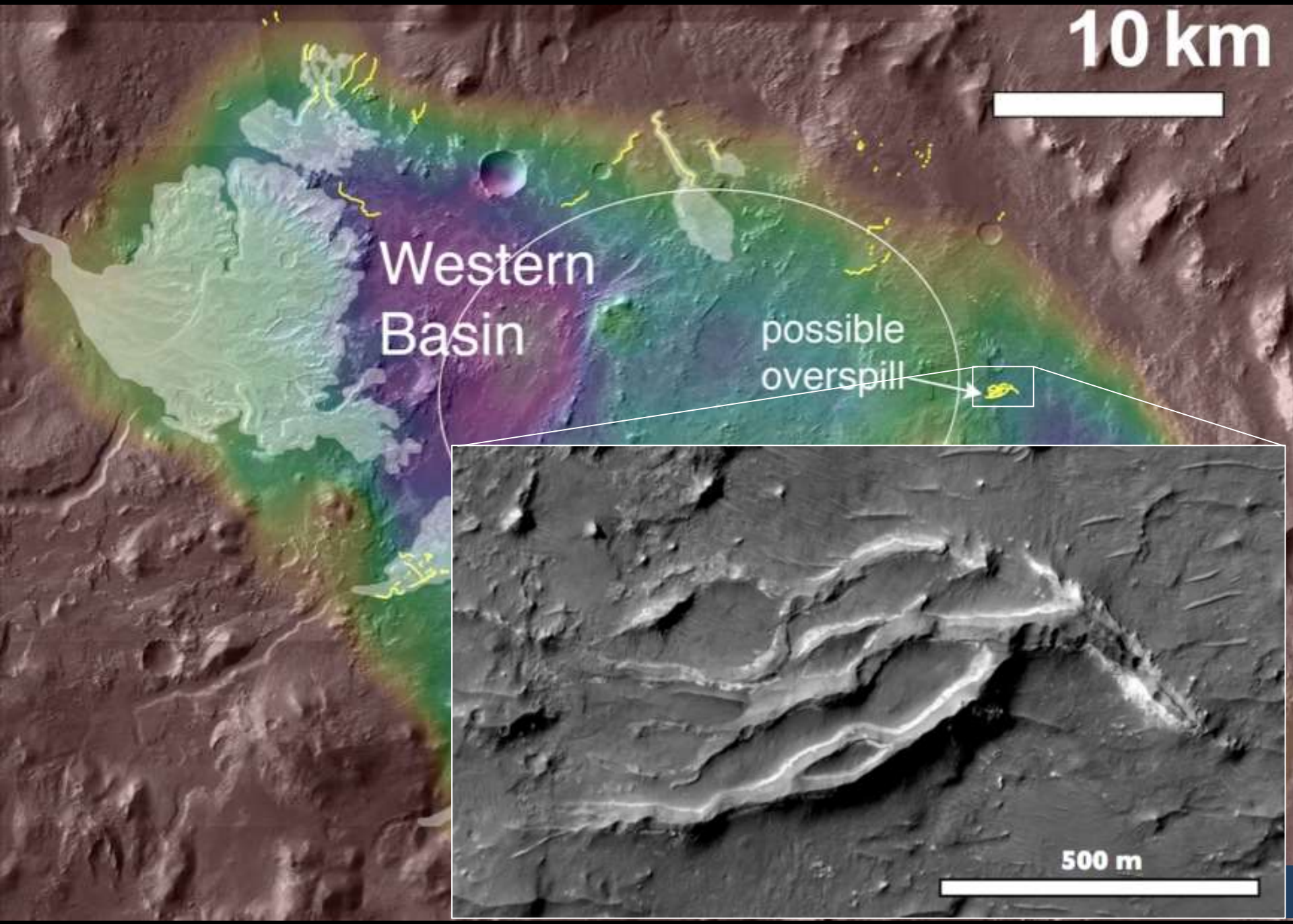
Rice et al., GRL (2011)

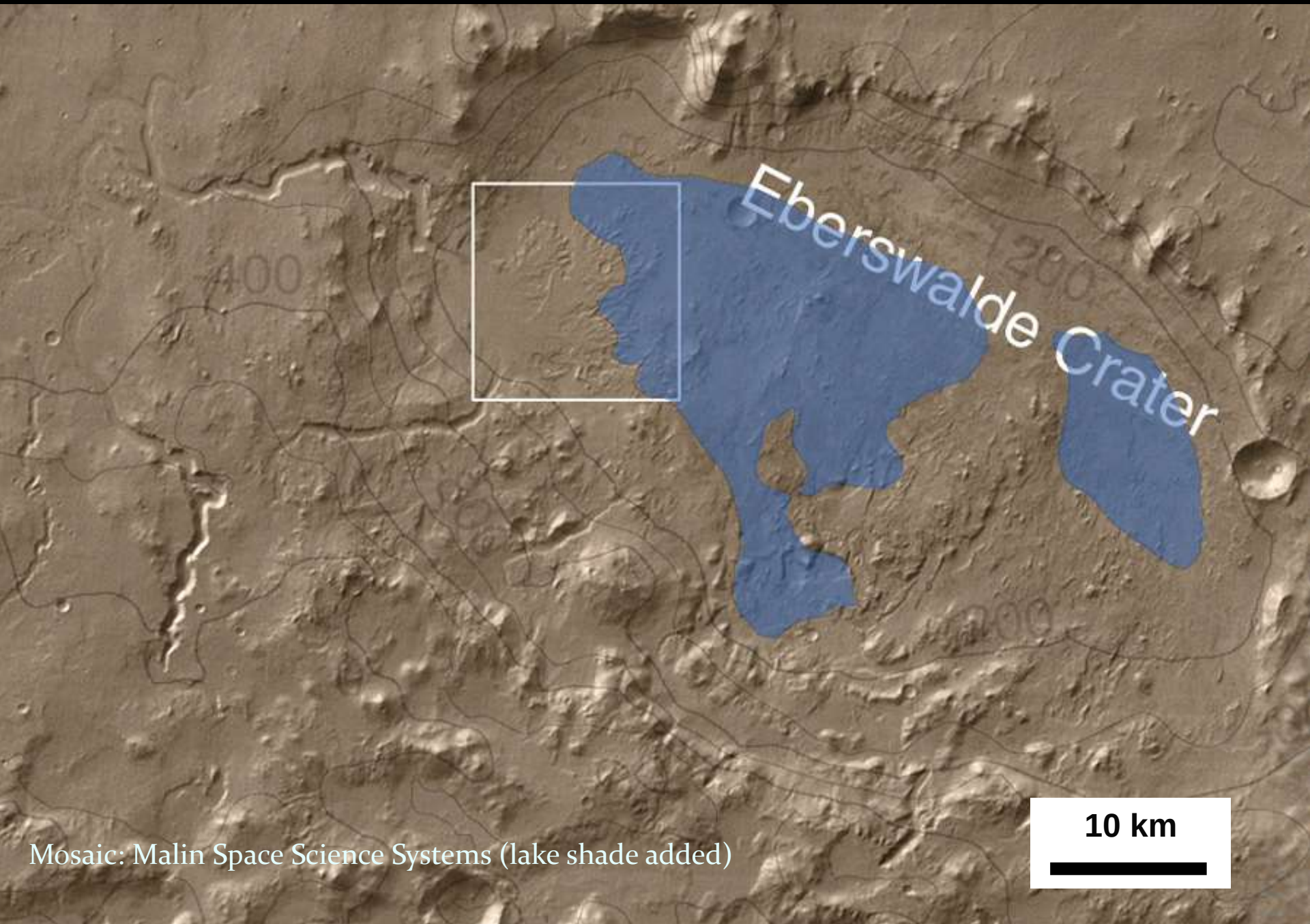
Evidence for fault-controlled topography



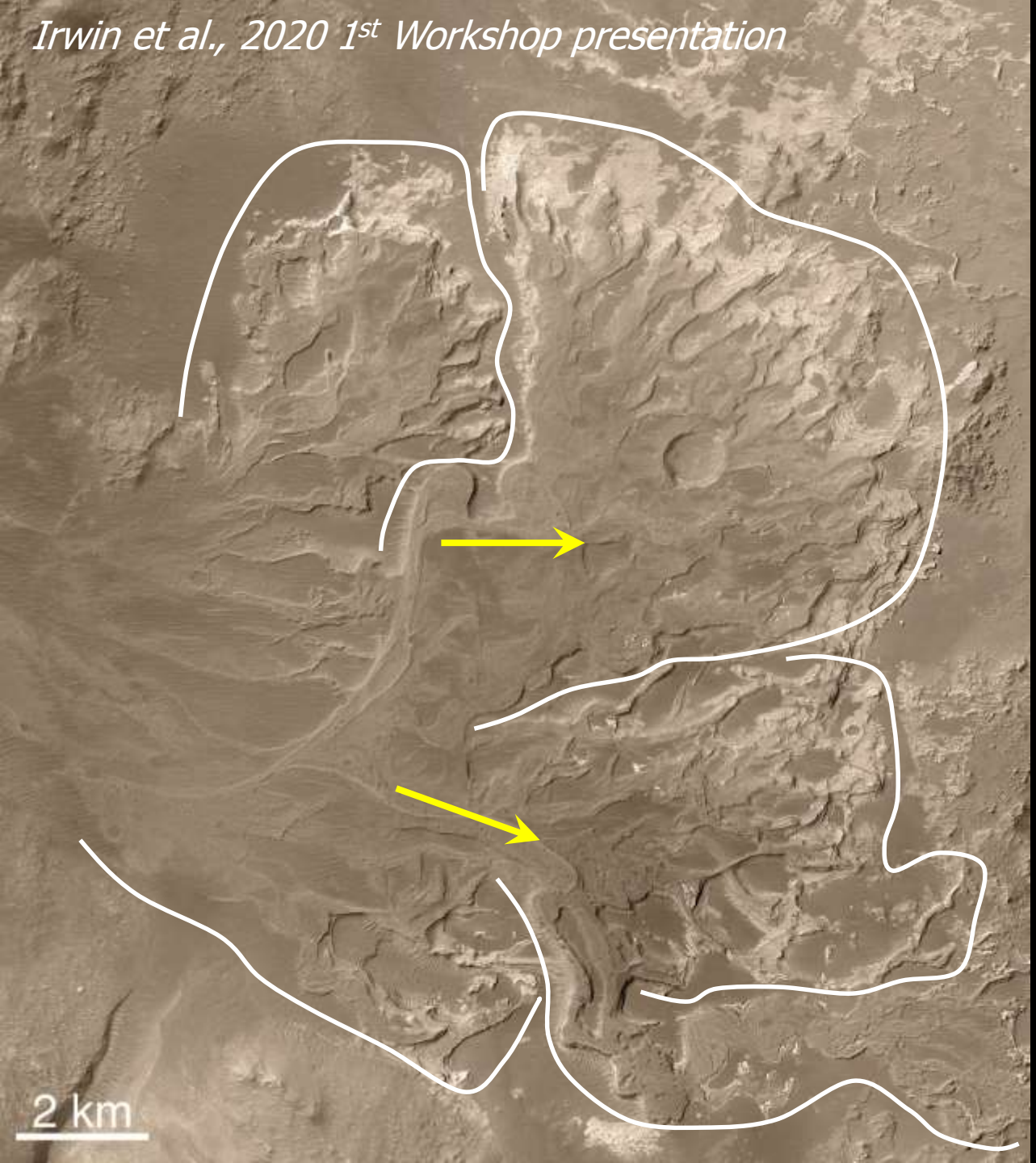


Rice et al. 2013


10 km
Western
Basin
possible
overspill
500 m



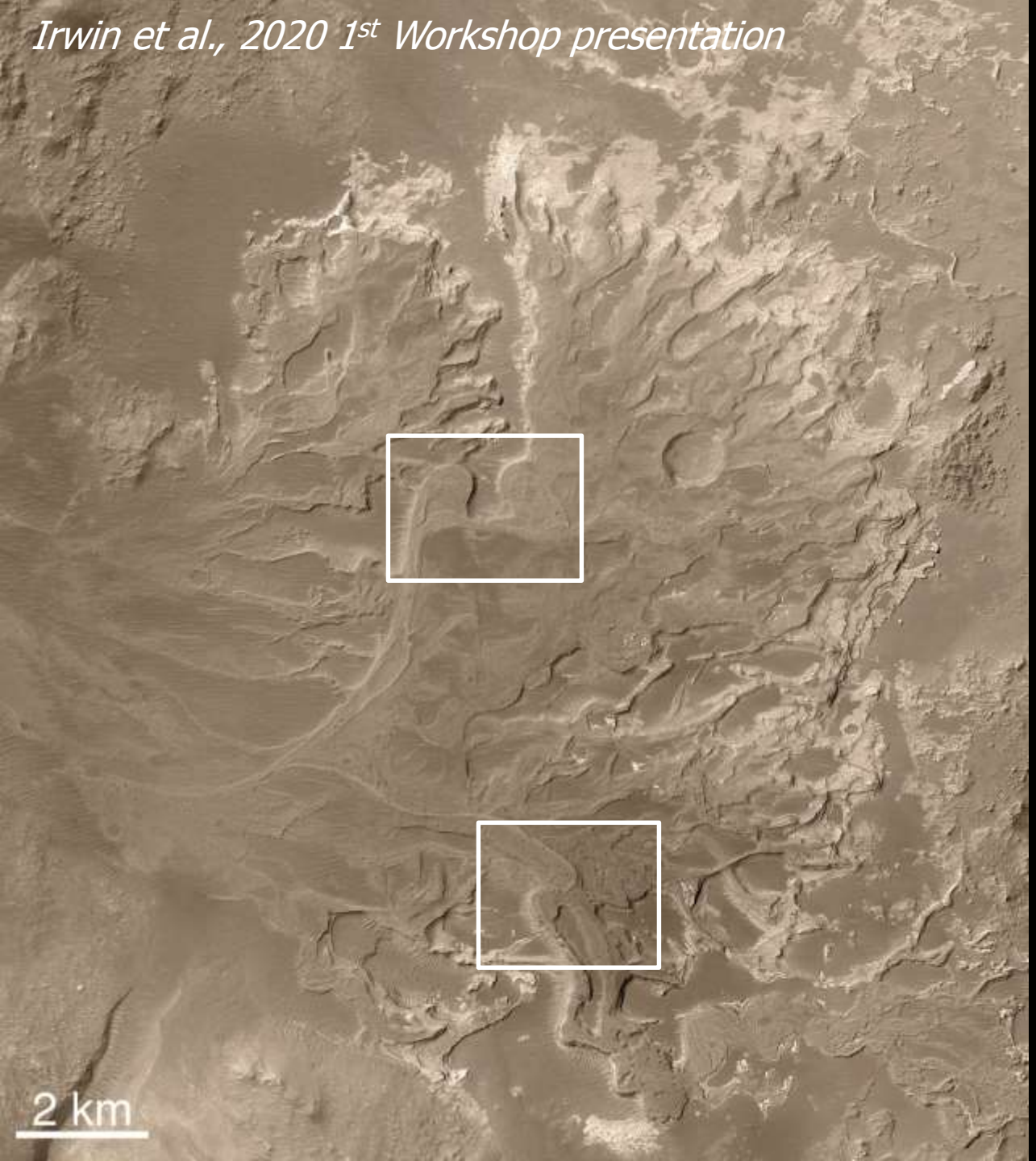
Mosaic: Malin Space Science Systems (lake shade added)



Major Lobes

Late transportive paleochannels

Mosaic:
Malin Space
Science Systems

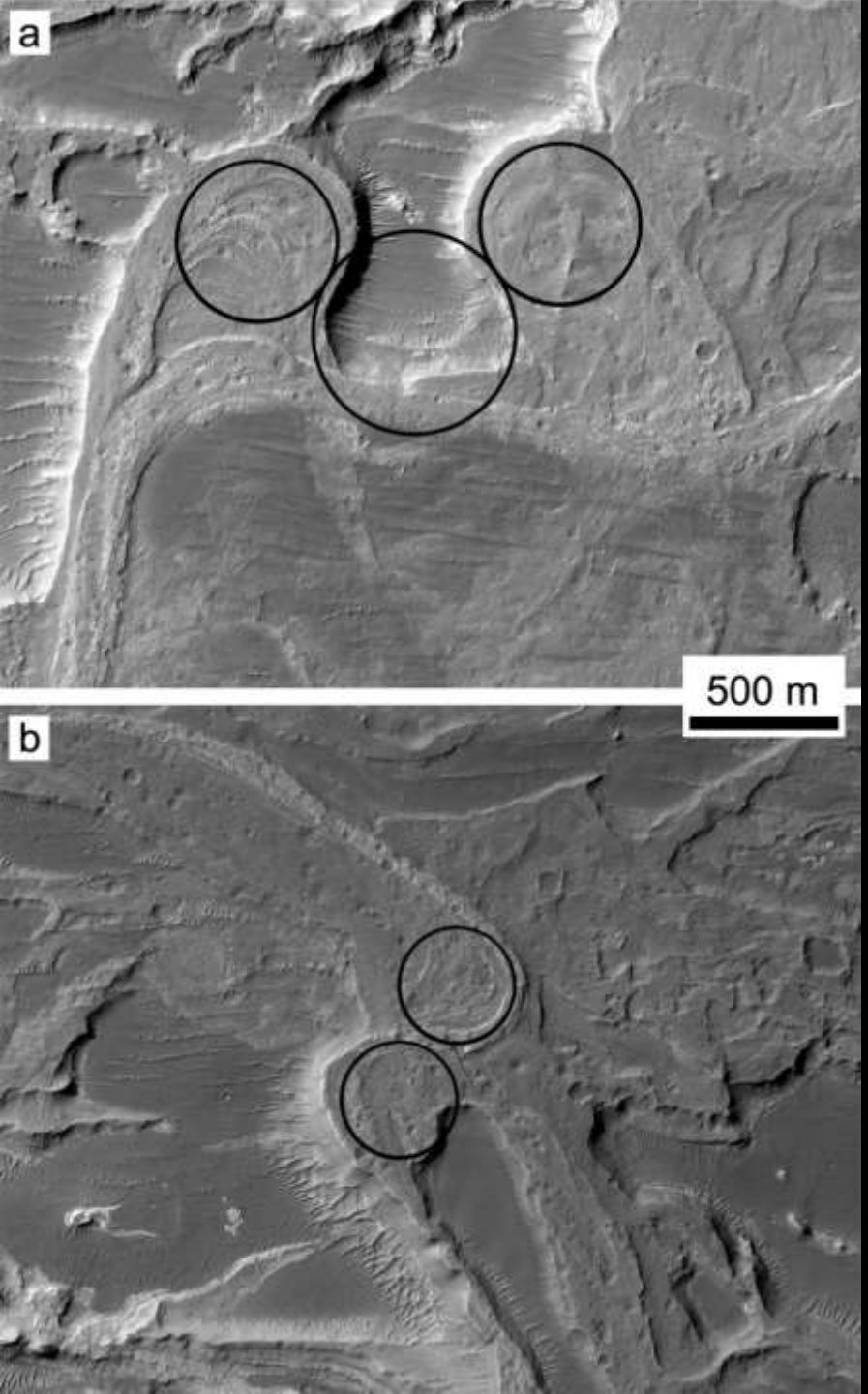


MEANDERS

Mosaic:
Malin Space
Science Systems

MEANDERS

Require cohesion from ice, clays, or cements, (or, on Earth, vegetation)



Songhua River, China (Google)

Irwin et al., 2020 1st Workshop presentation

Eberswalde Crater Paleohydrology

Width-wavelength relationships in two inverted paleochannels

Consistent with meande

Inverted channels are w

Bank-full flow for invert

From width: 450 m^3/s (n

From wavelength: 400 m

Annual runoff (lake leve

For evaporation of 1 m/y

For evaporation of 0.1 m

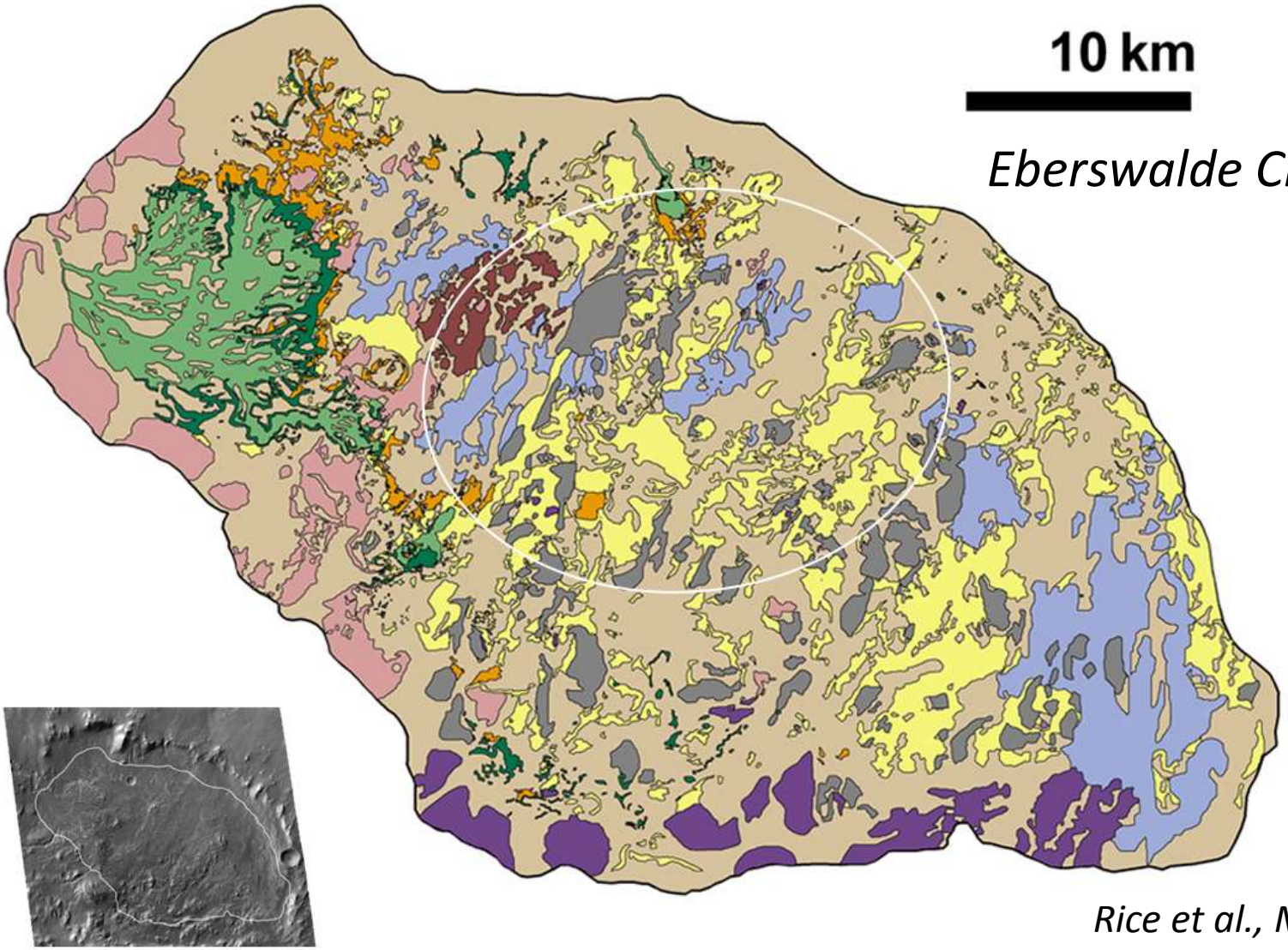
Deposition timescale (deposit volume of 6 km^3)

For water/sediment volume ratio of 1,000: tens to hundreds of thousands of years

For water/sediment volume ratio of 10,000: hundreds of thousands to millions of yrs

- Duration of deposition: 10^4 – 10^6 yr
- Annual runoff production (intermittent) about 1-20 cm/year
- Annual snowmelt or infrequent moderate rainfall are possible

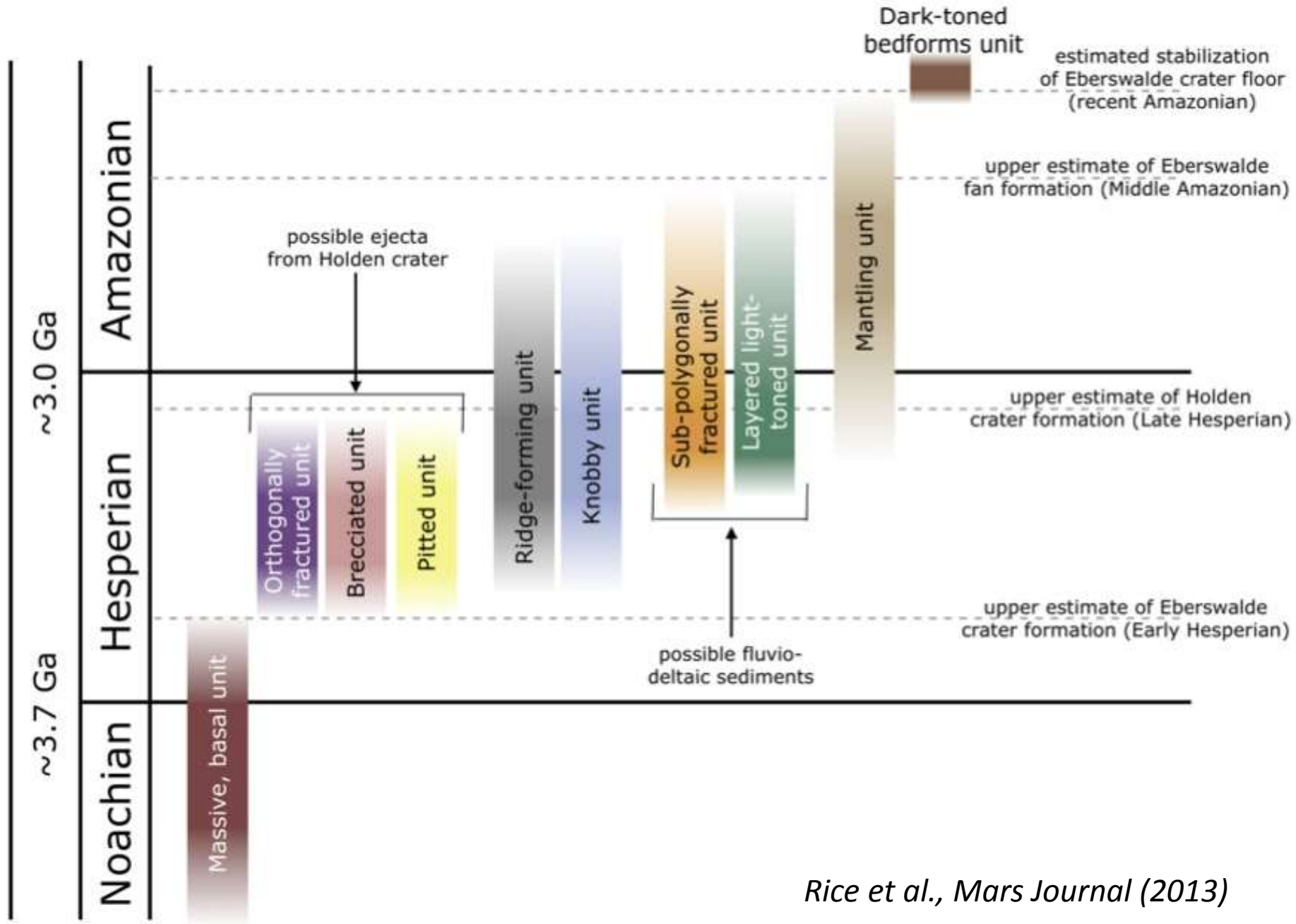
Irwin et al. (2013)



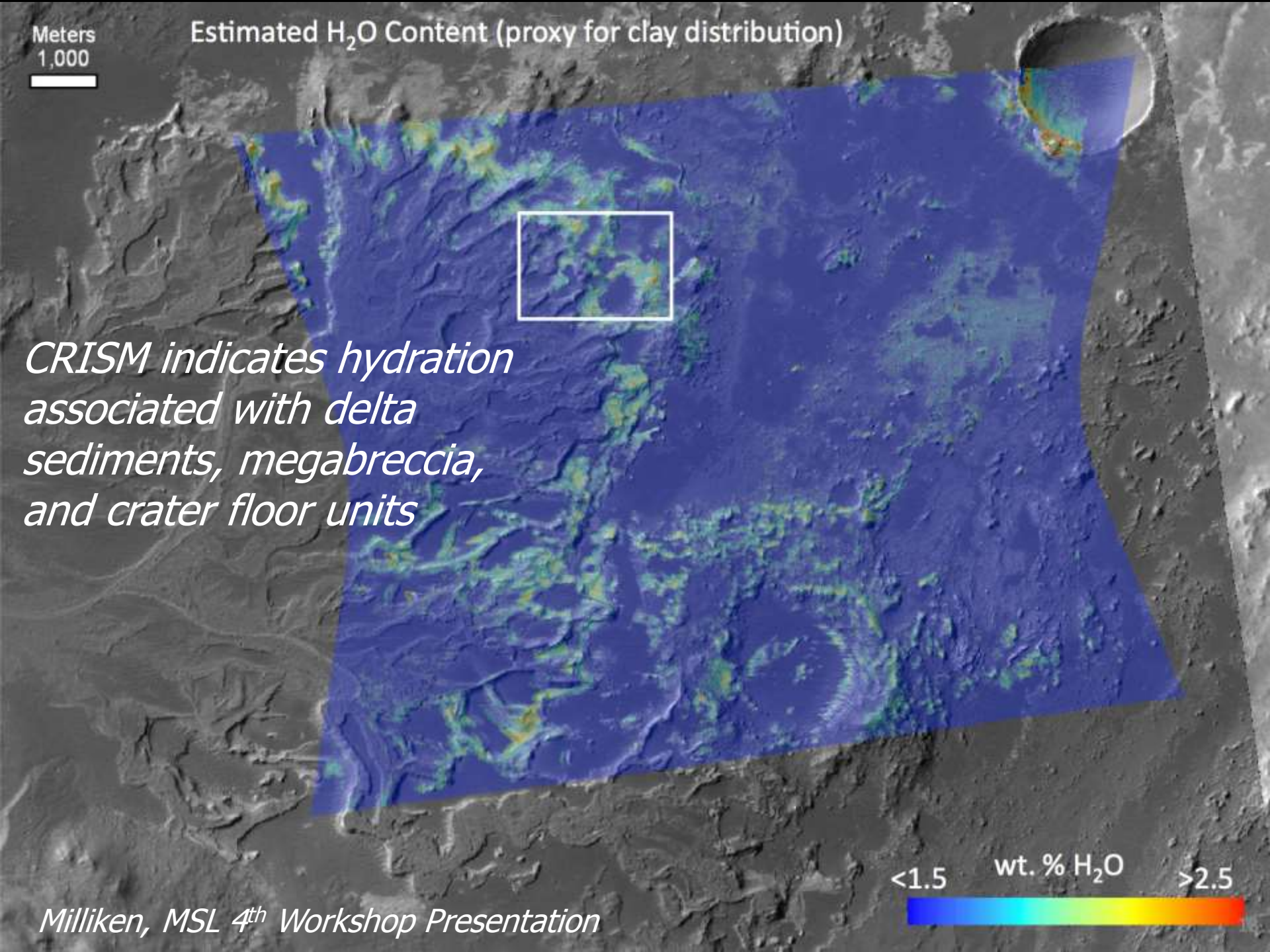
Eberswalde Crater Unit Map

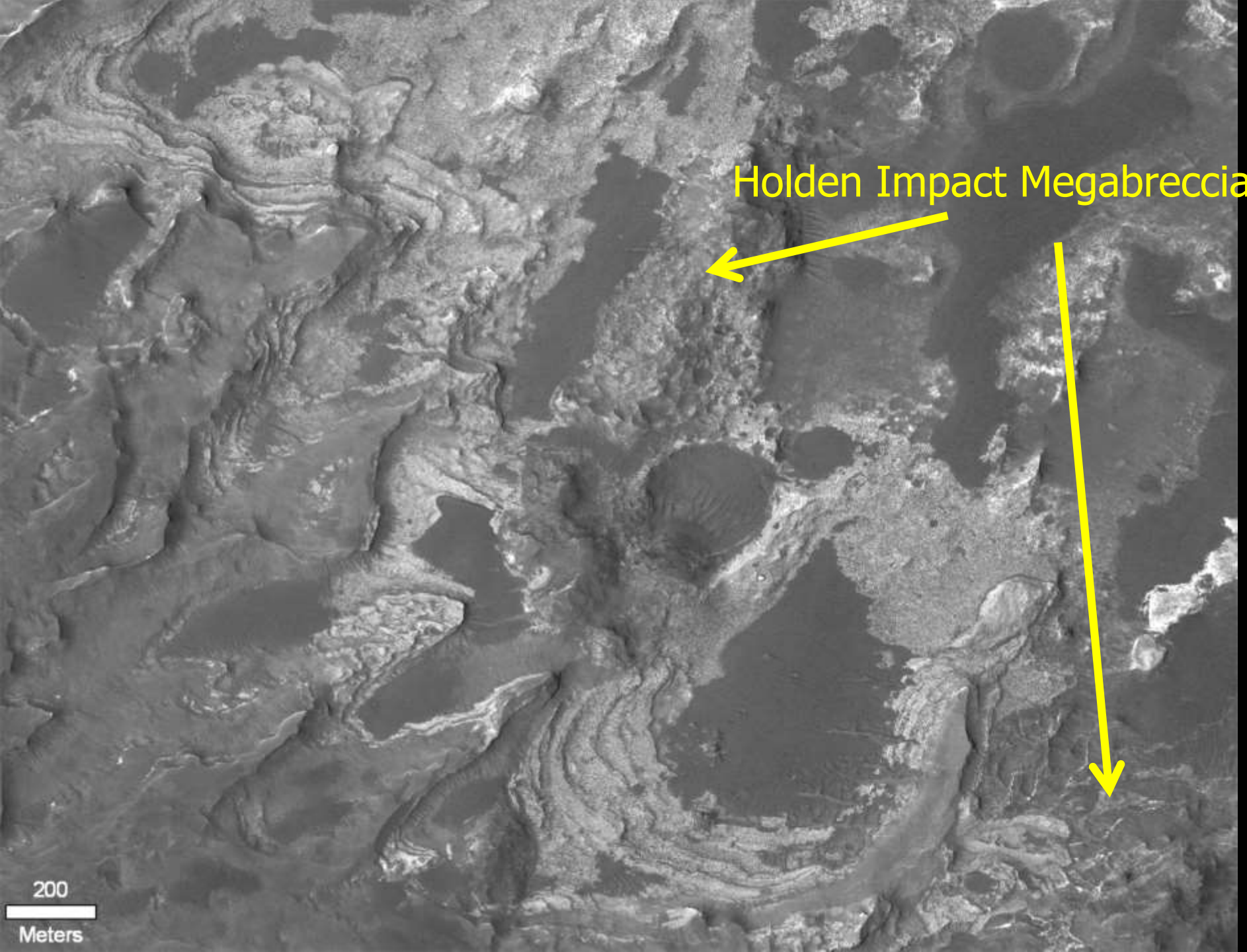
Rice et al., Mars Journal (2013)

- *Dark-toned bedforms unit*
- *Mantling unit*
- *Layered light-toned unit / Thinly-mantled layered unit*
- *Sub-polygonally fractured unit*
- *Knobby unit*
- *Ridge-forming unit*
- *Pitted unit*
- *Brecciated unit*
- *Orthogonally fractured unit*
- *Massive basal unit*



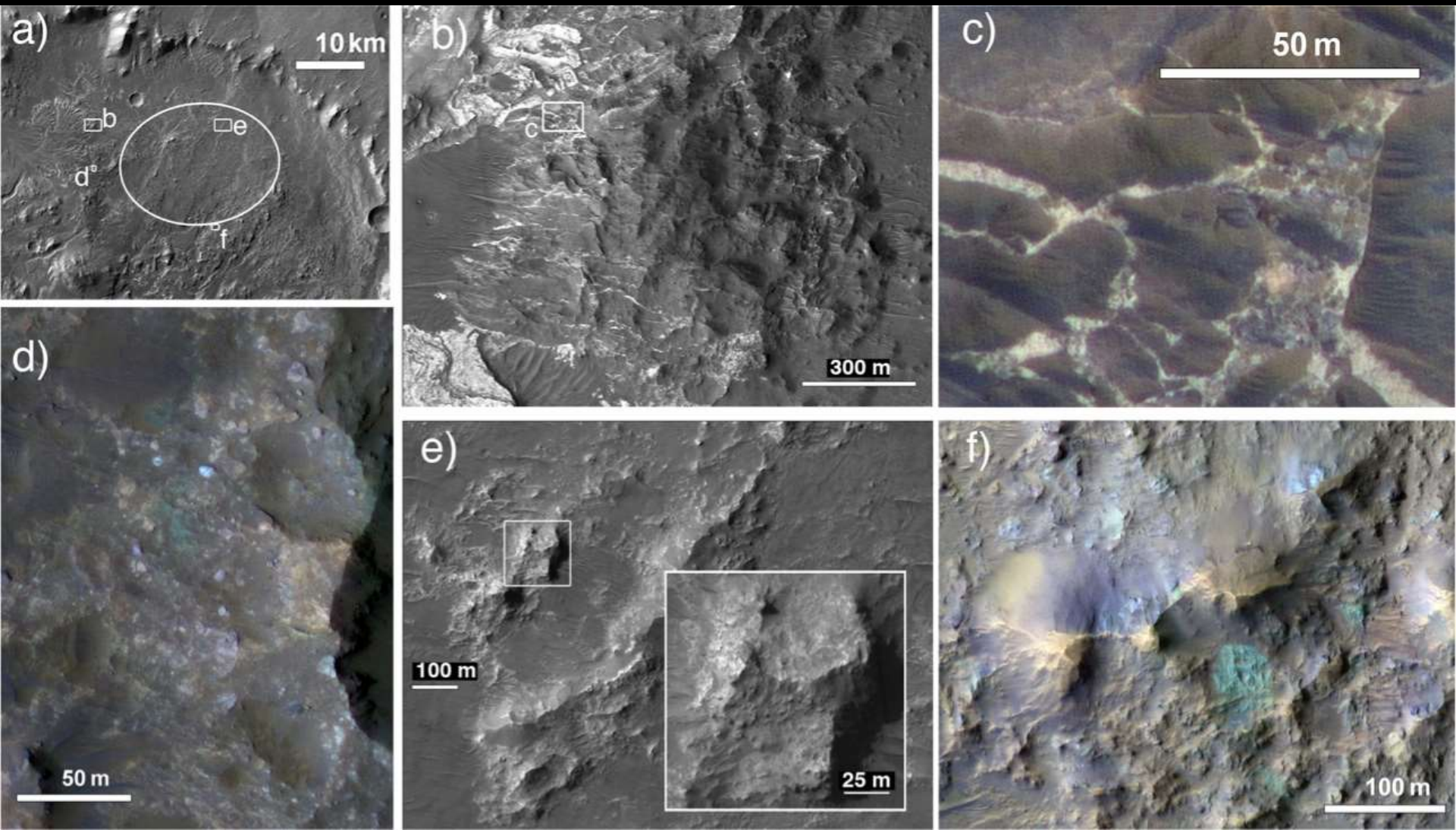
Rice et al., Mars Journal (2013)

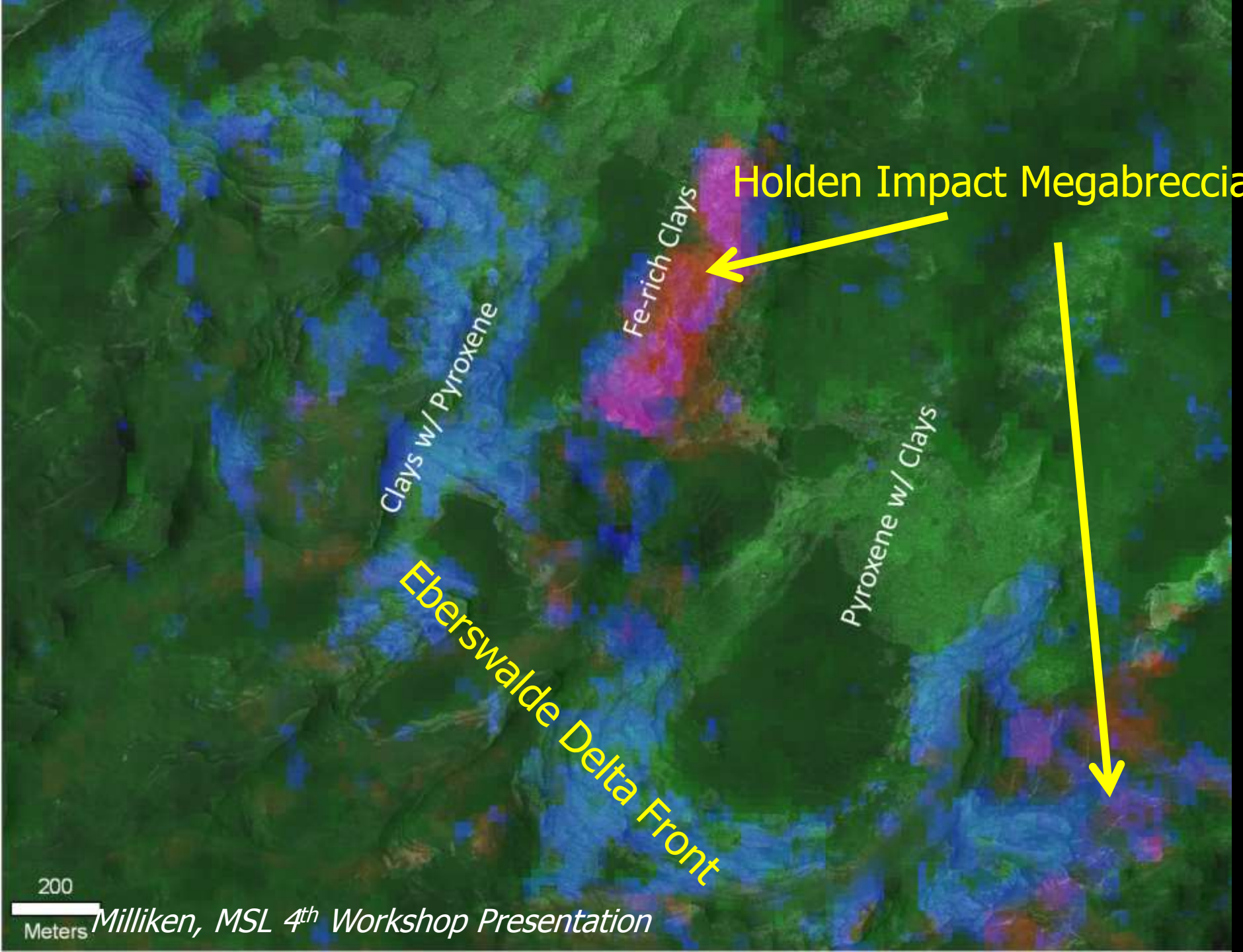

Meters
1,000
Estimated H_2O Content (proxy for clay distribution)
CRISM indicates hydration associated with delta sediments, megabreccia, and crater floor units
<1.5
wt. % H_2O
>2.5
Milliken, MSL 4th Workshop Presentation

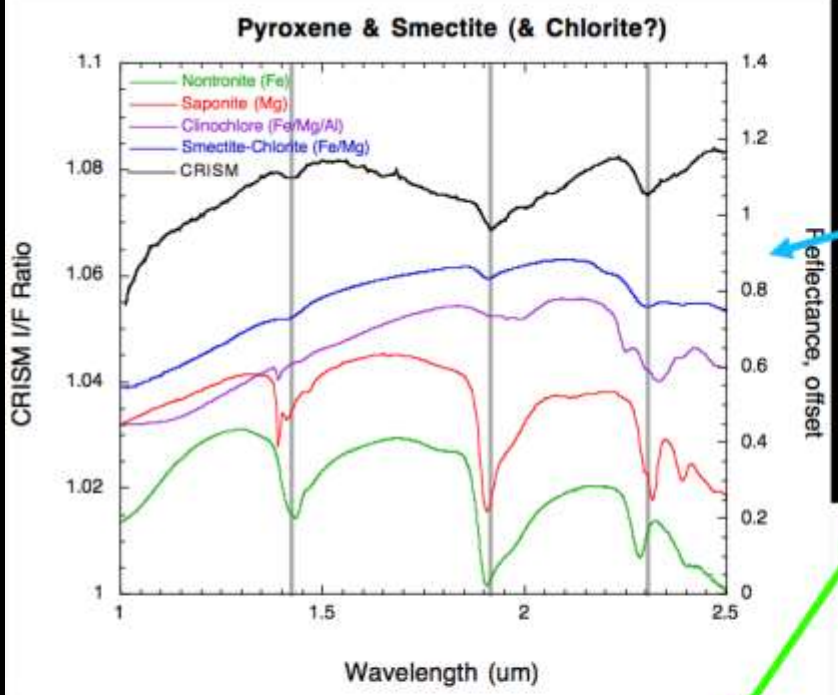

Holden Impact Megabreccia
200
Meters

Examples of megabreccia from the Holden-forming impact. Hydrothermal(?) veins observed in many locations

Rice et al., Mars Journal (2013)




Holden Impact Megabreccia
Fe-rich Clays
Clays w/ Pyroxene
Pyroxene w/ Clays
Eberswalde Delta Front
200
Meters
Milliken, MSL 4th Workshop Presentation

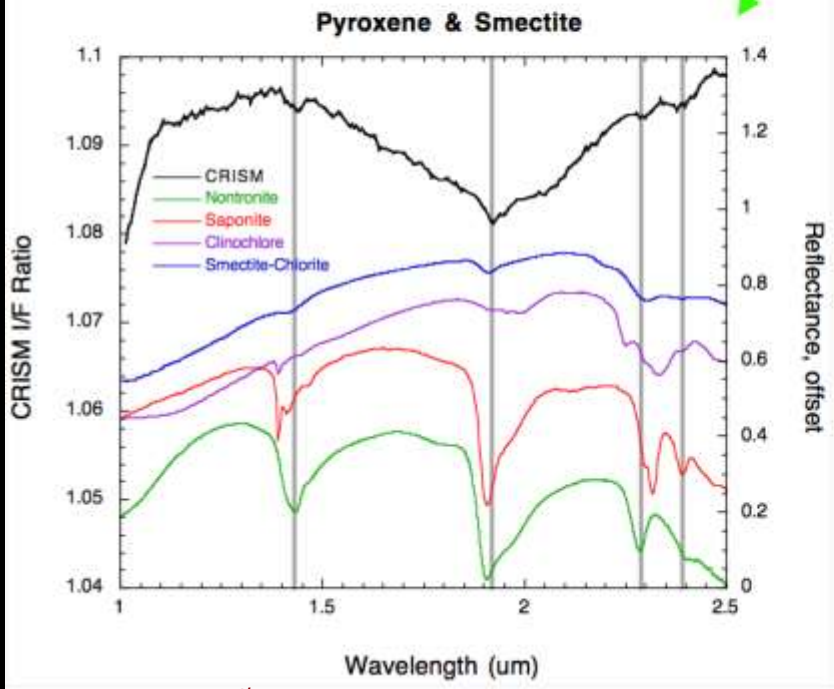


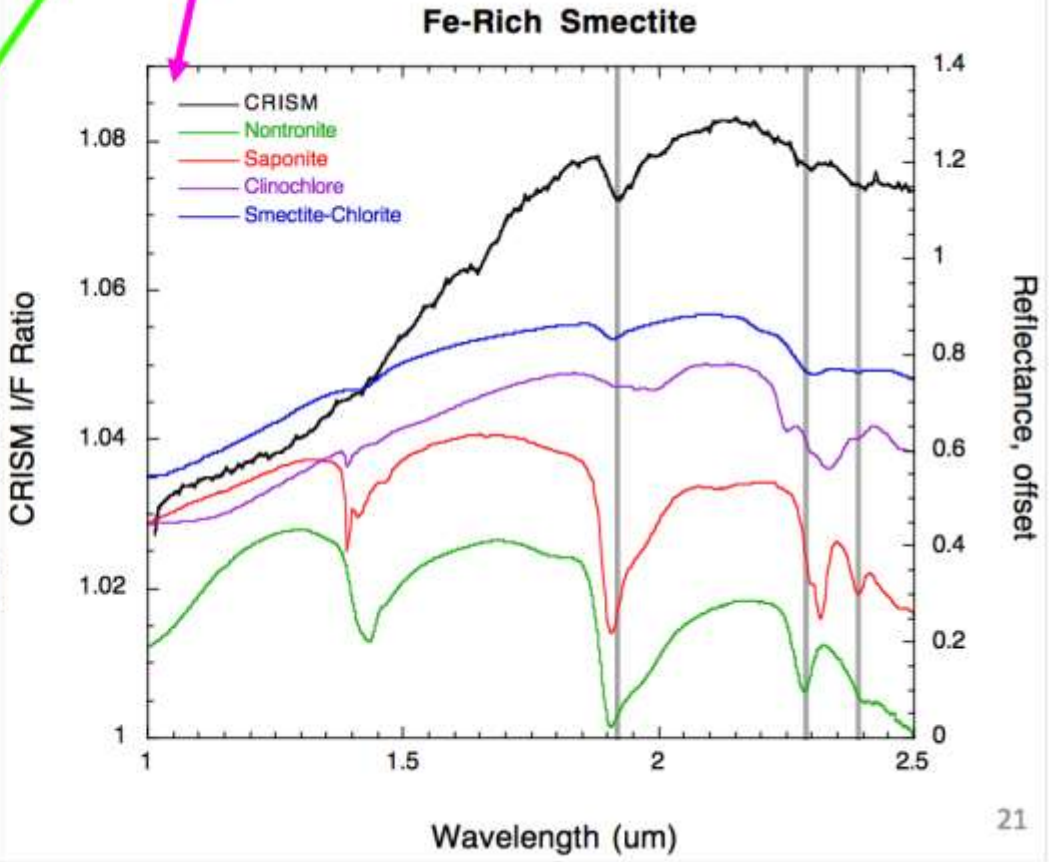
There are at least 3 distinct units:

-Clay-bearing unit with pyroxene

- Pyroxene unit with clays

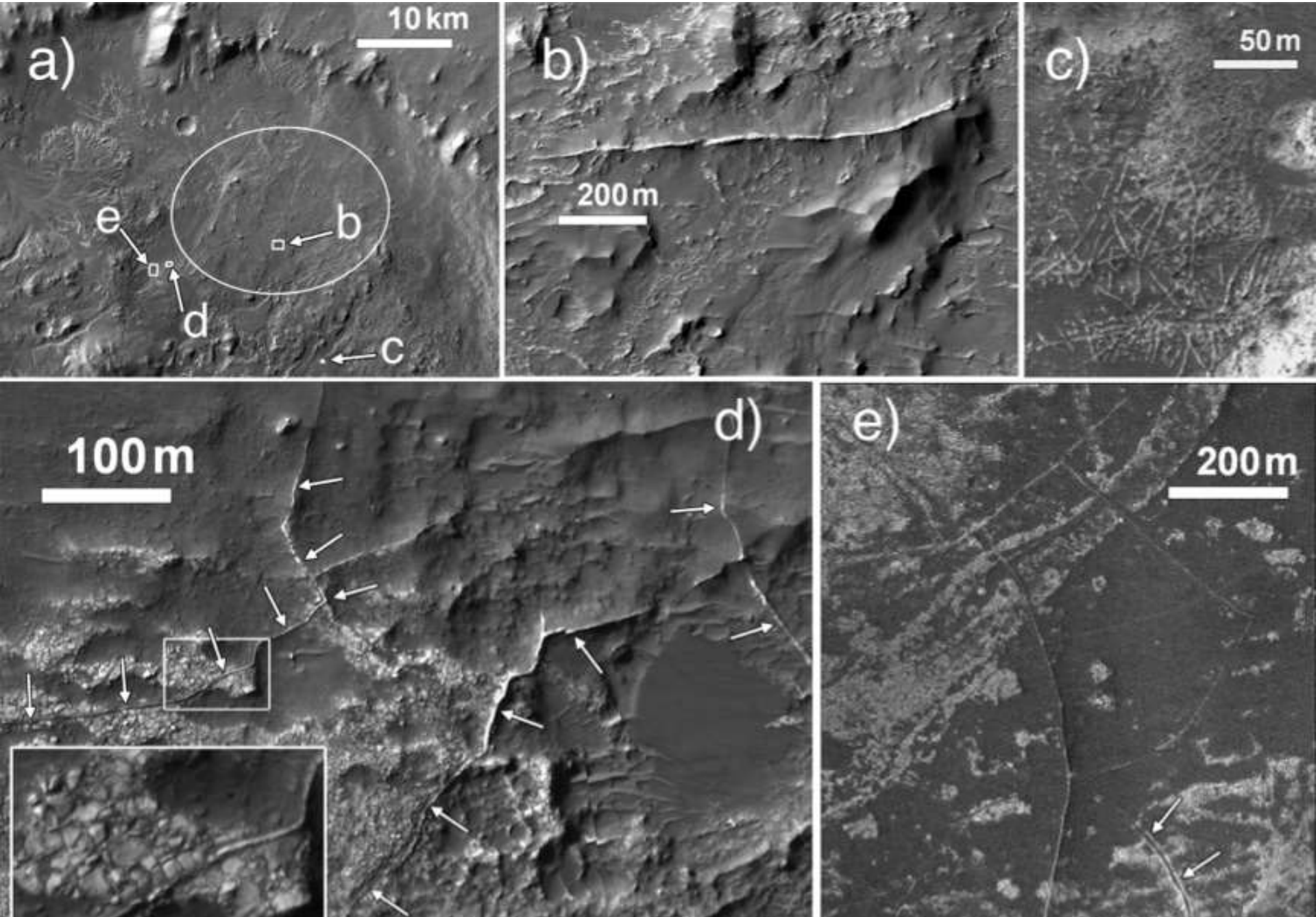
- Fe-rich clay unit

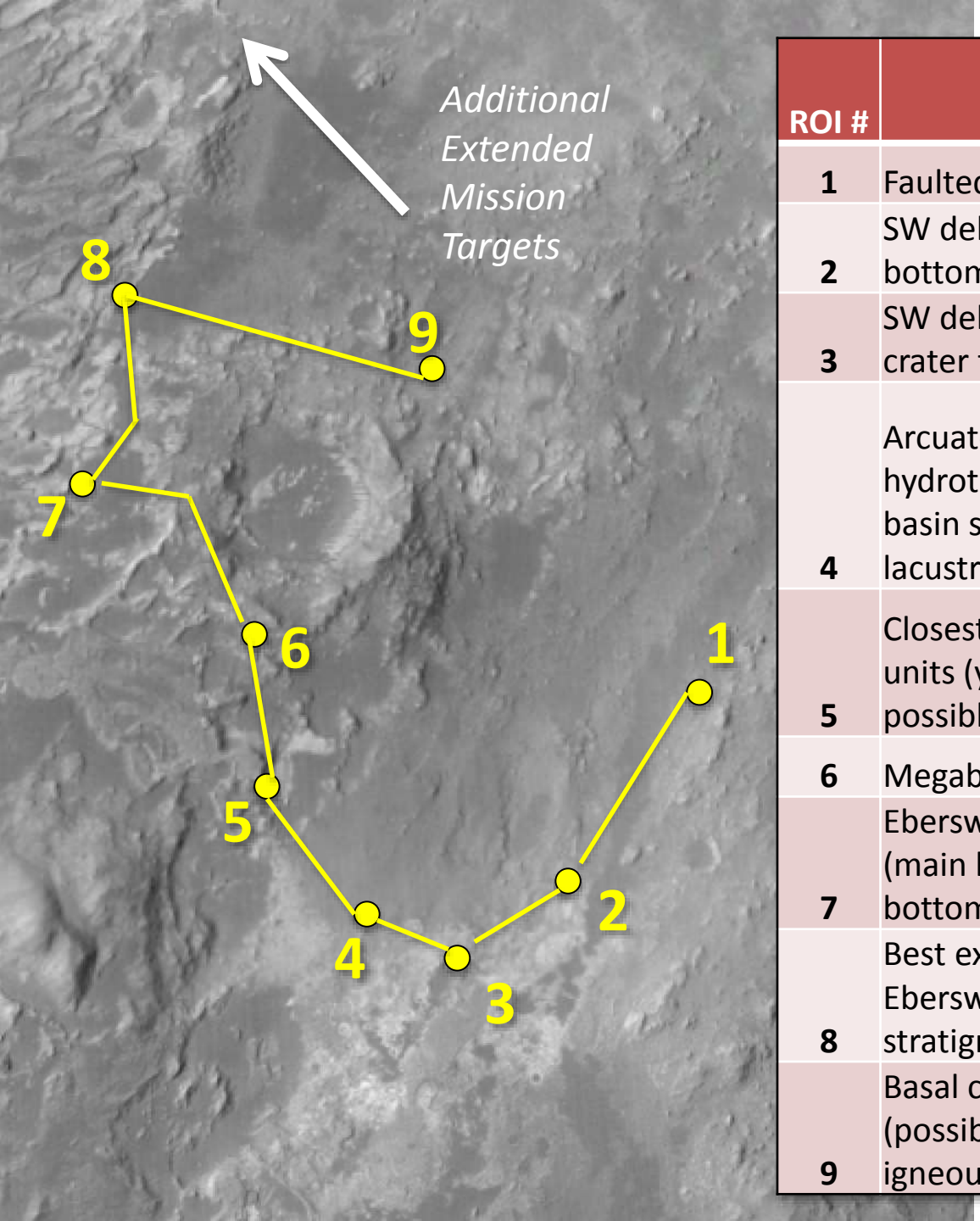




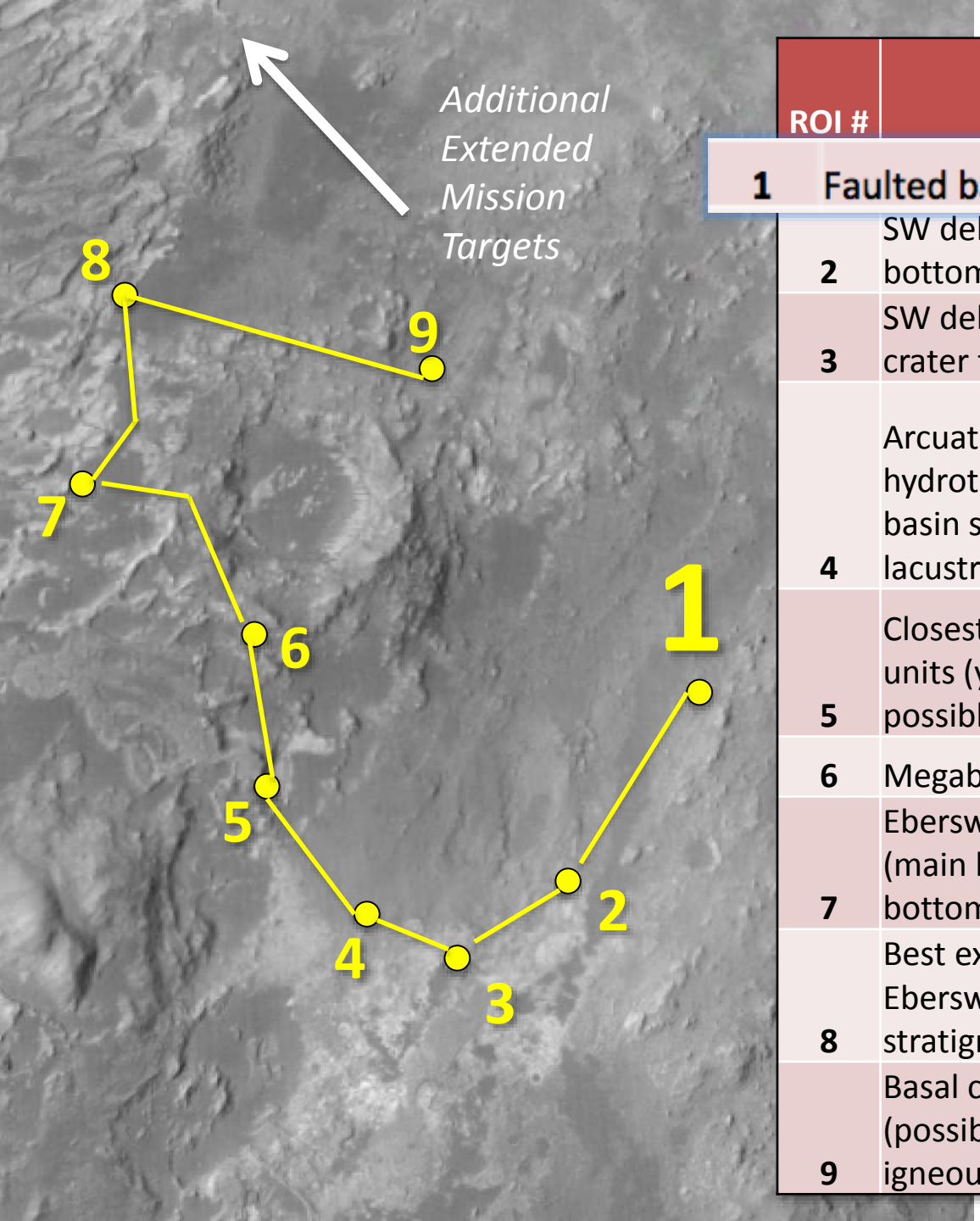
Veins: linear, curvilinear and boxwork forms

Rice et al., Mars Journal (2013)

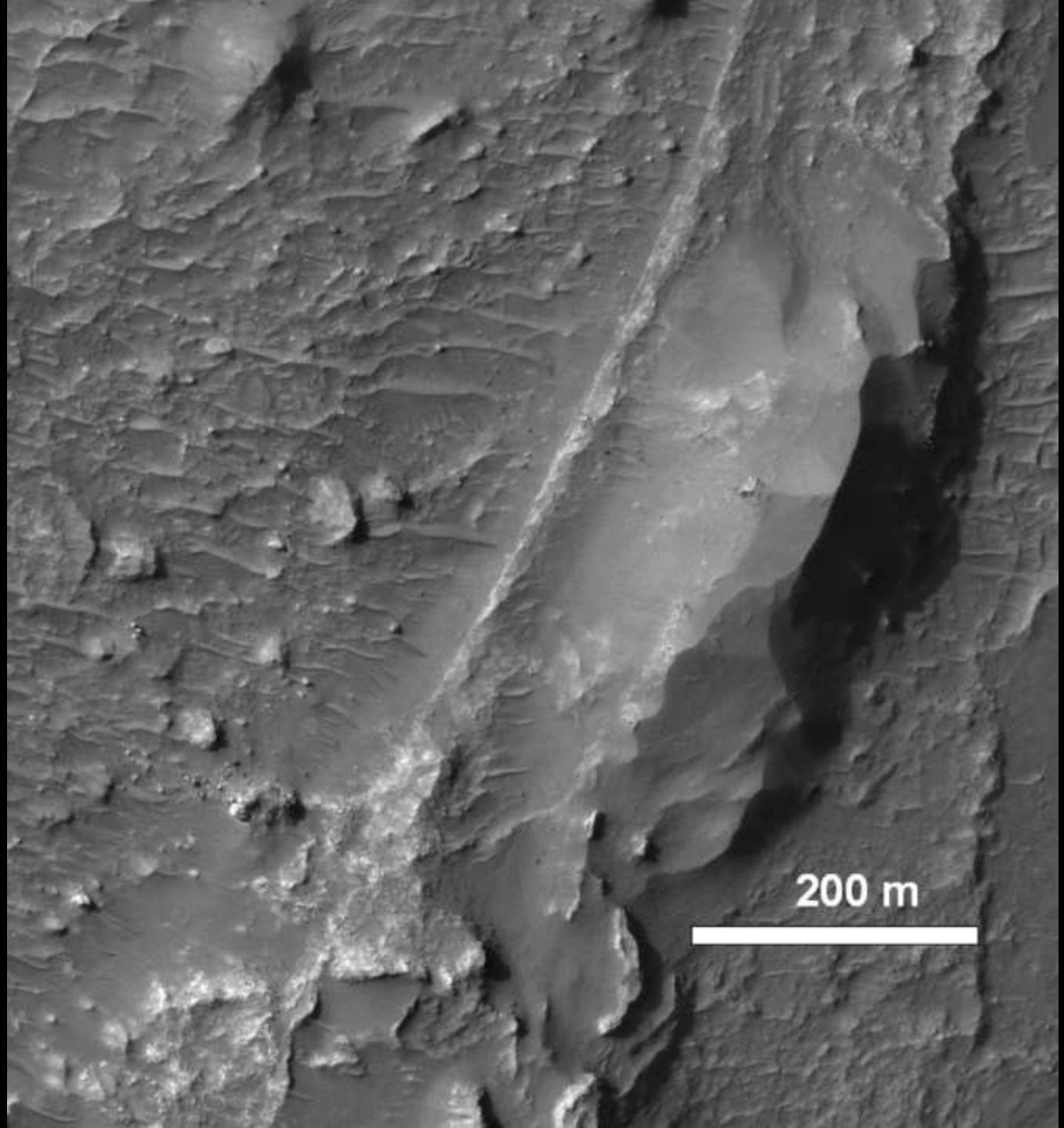


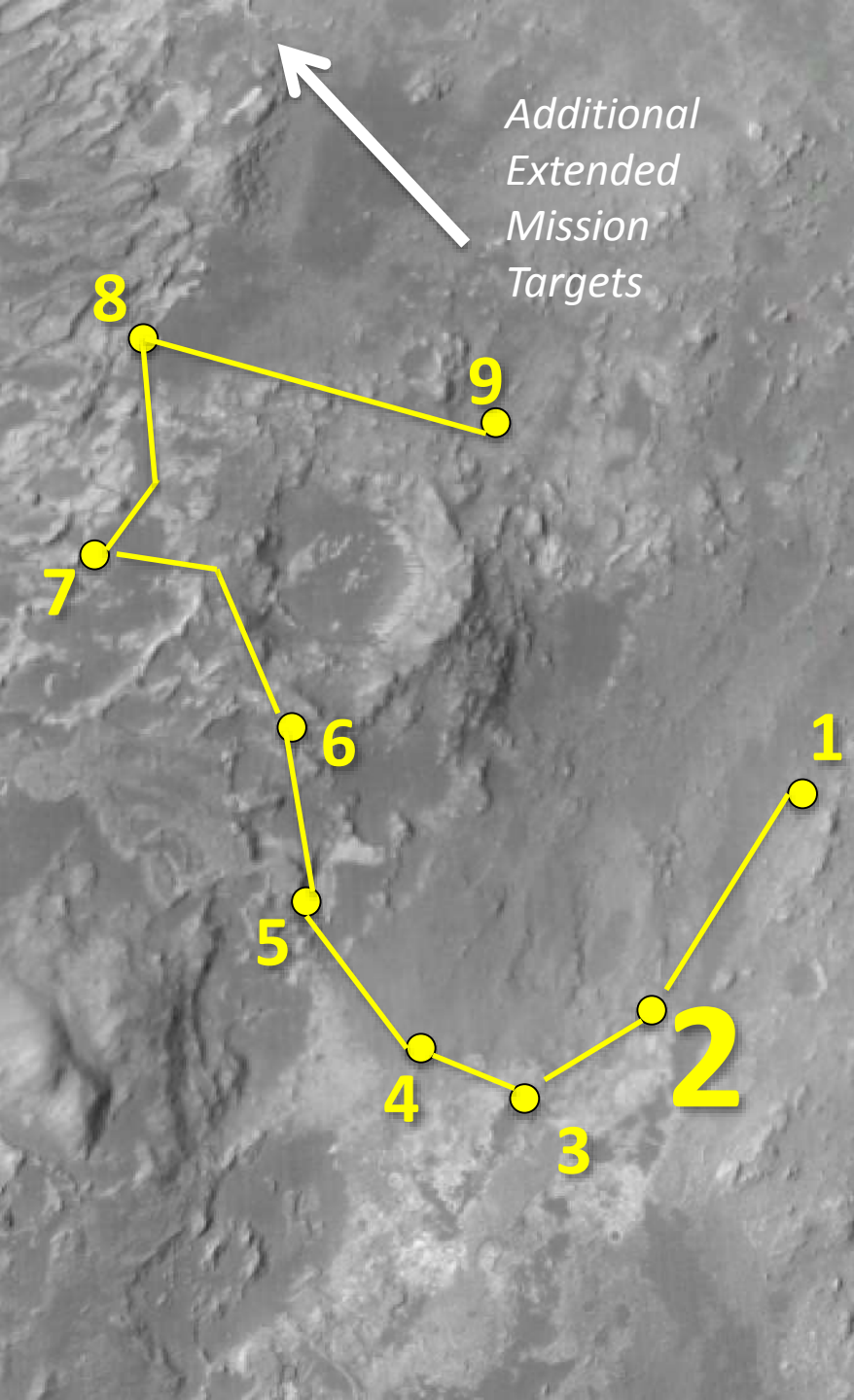


ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

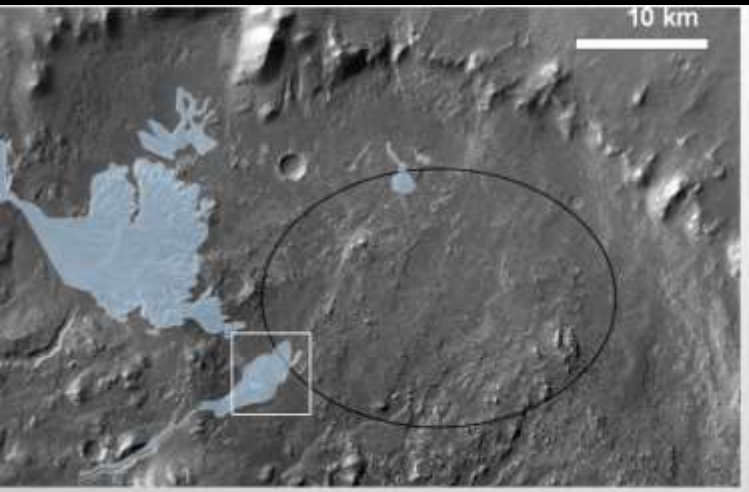


ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km


200 m

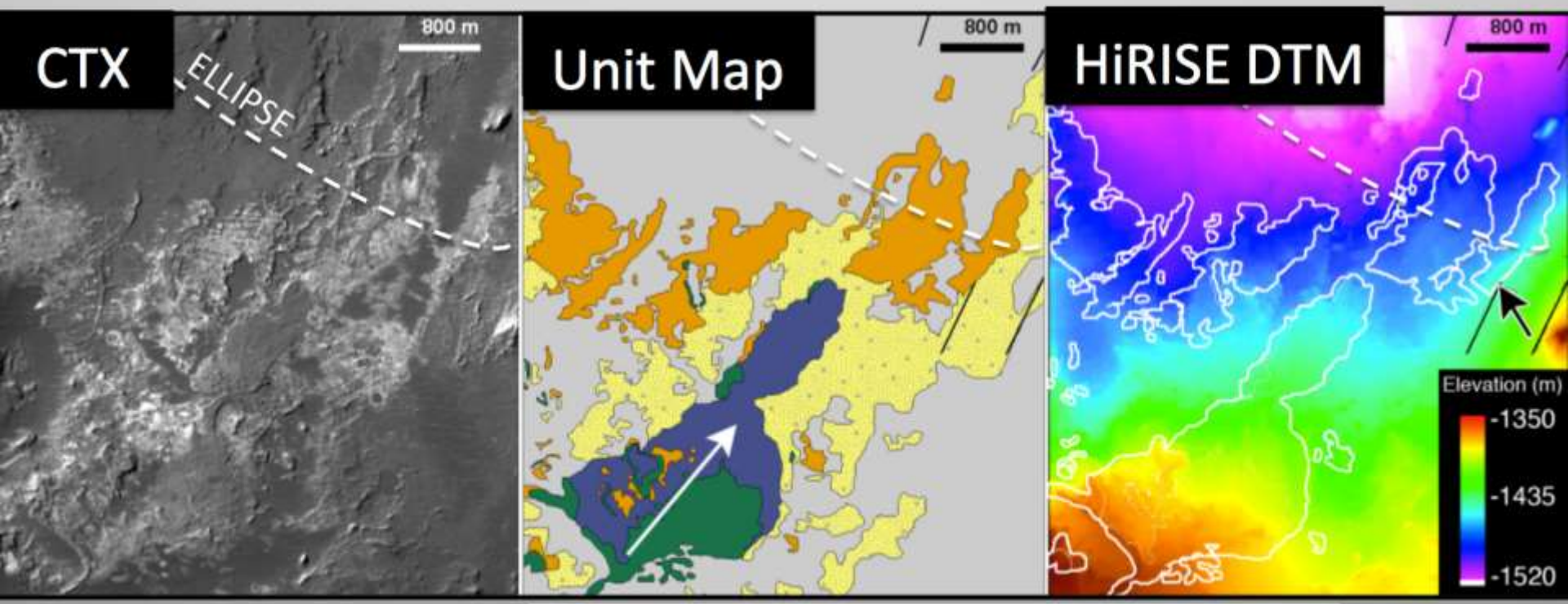


ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

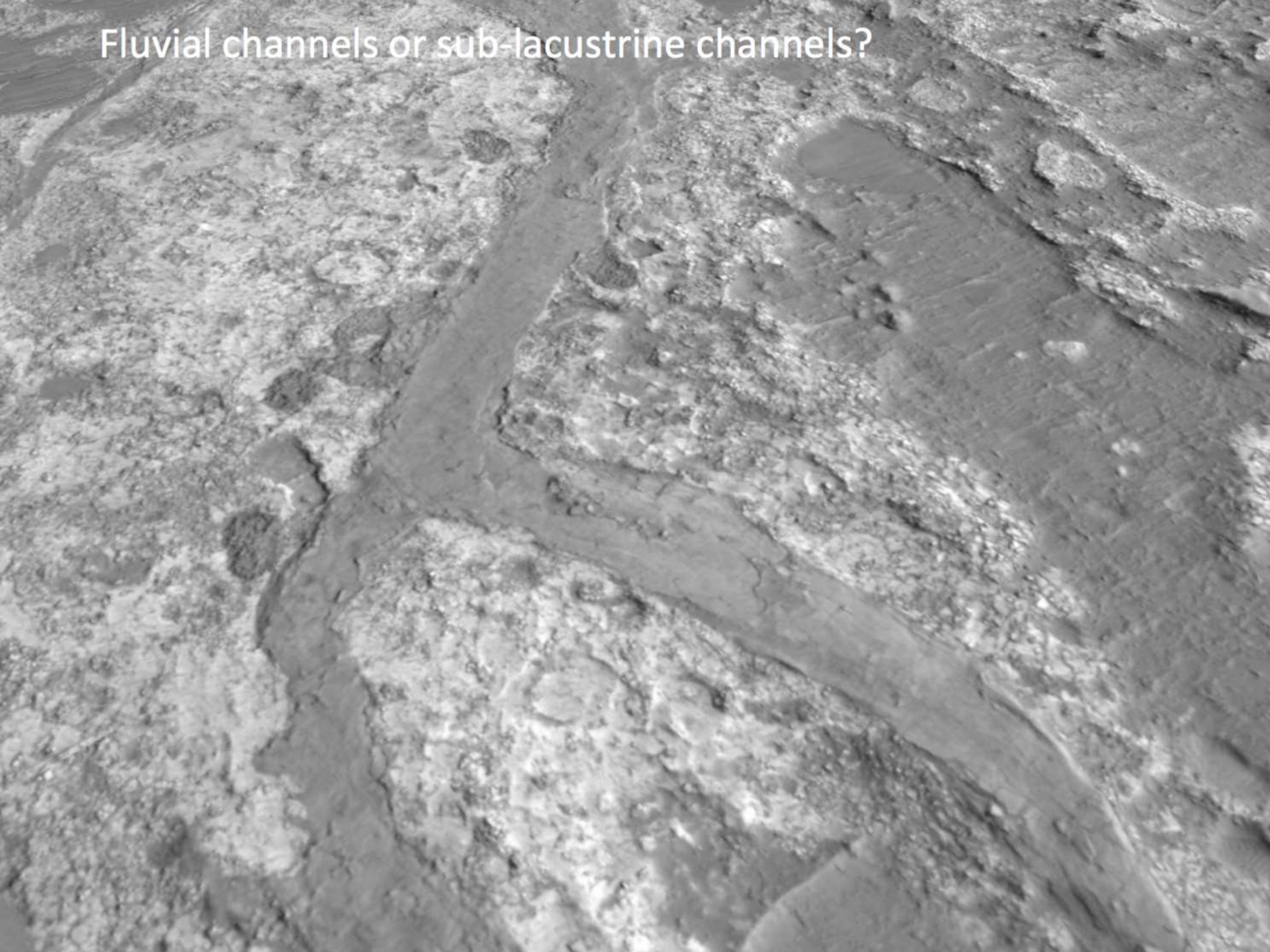


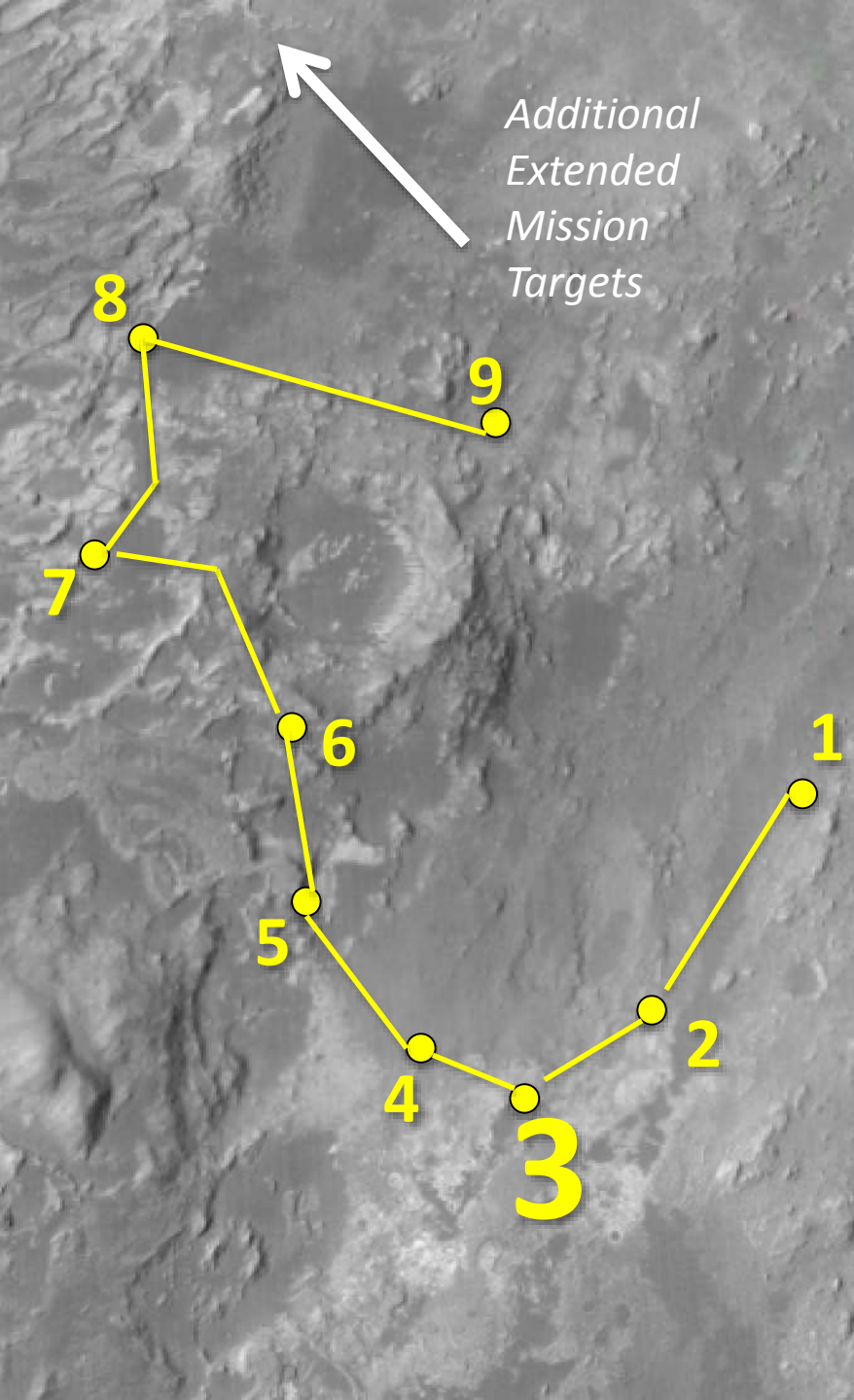
SW Delta system extends into landing ellipse

- Fluvio-deltaic system extends ~ 1 km within the landing ellipse
- Front of putative delta at -1450 m, in the deep Western Basin
- Sediments overlay possible faults in the pitted unit

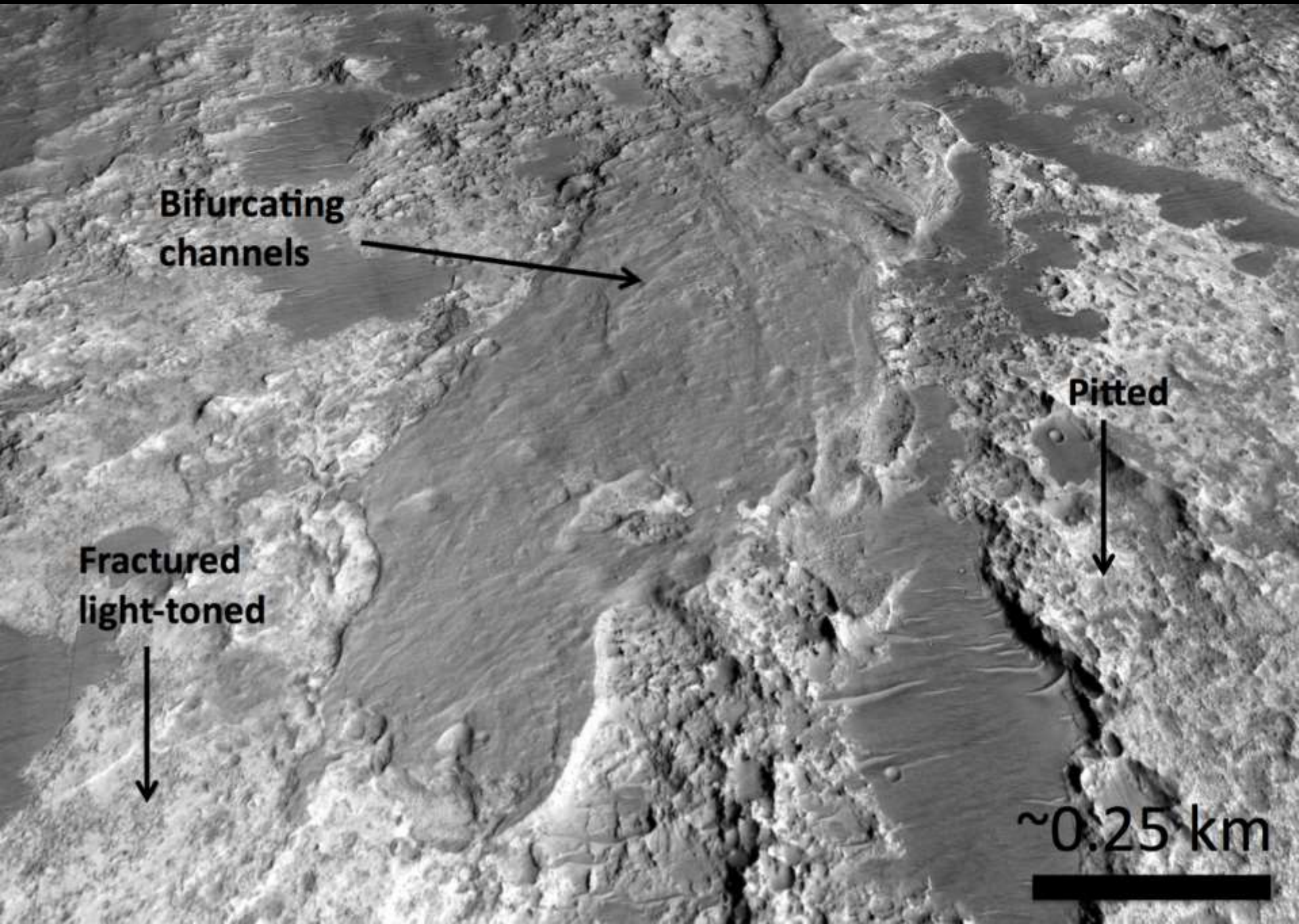


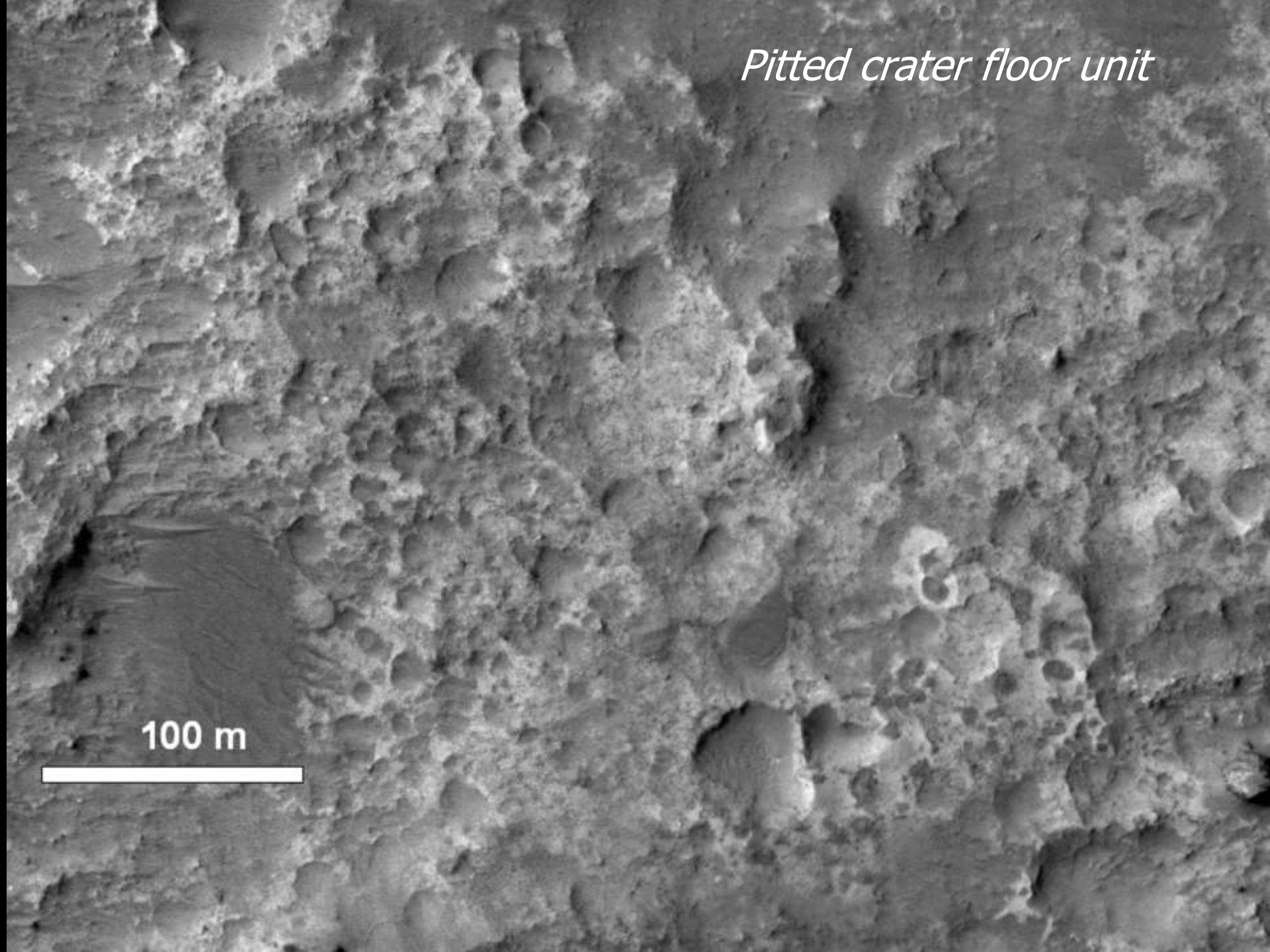
Rice et al., GRL (2011)

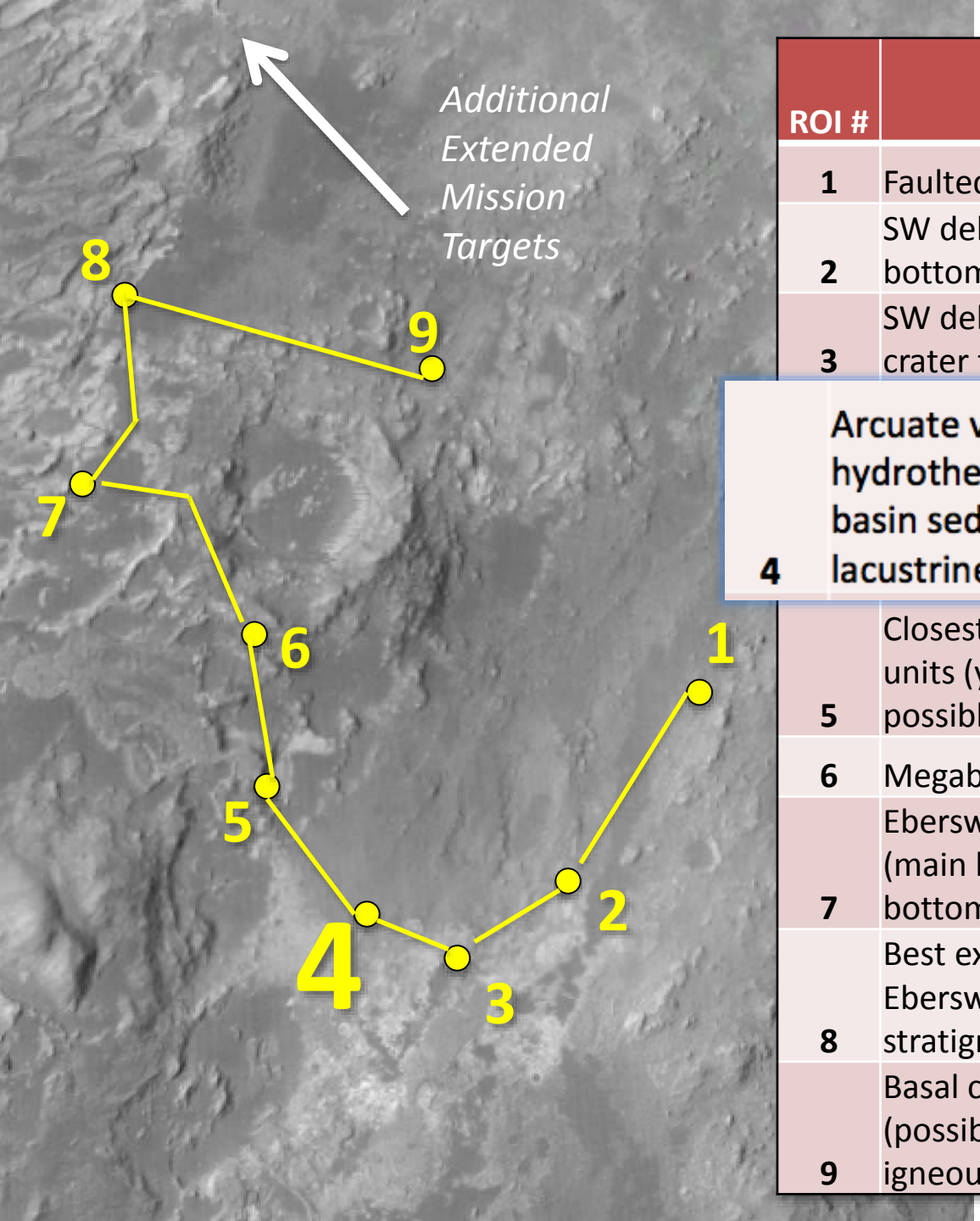

Fluvial channels or sub-lacustrine channels?



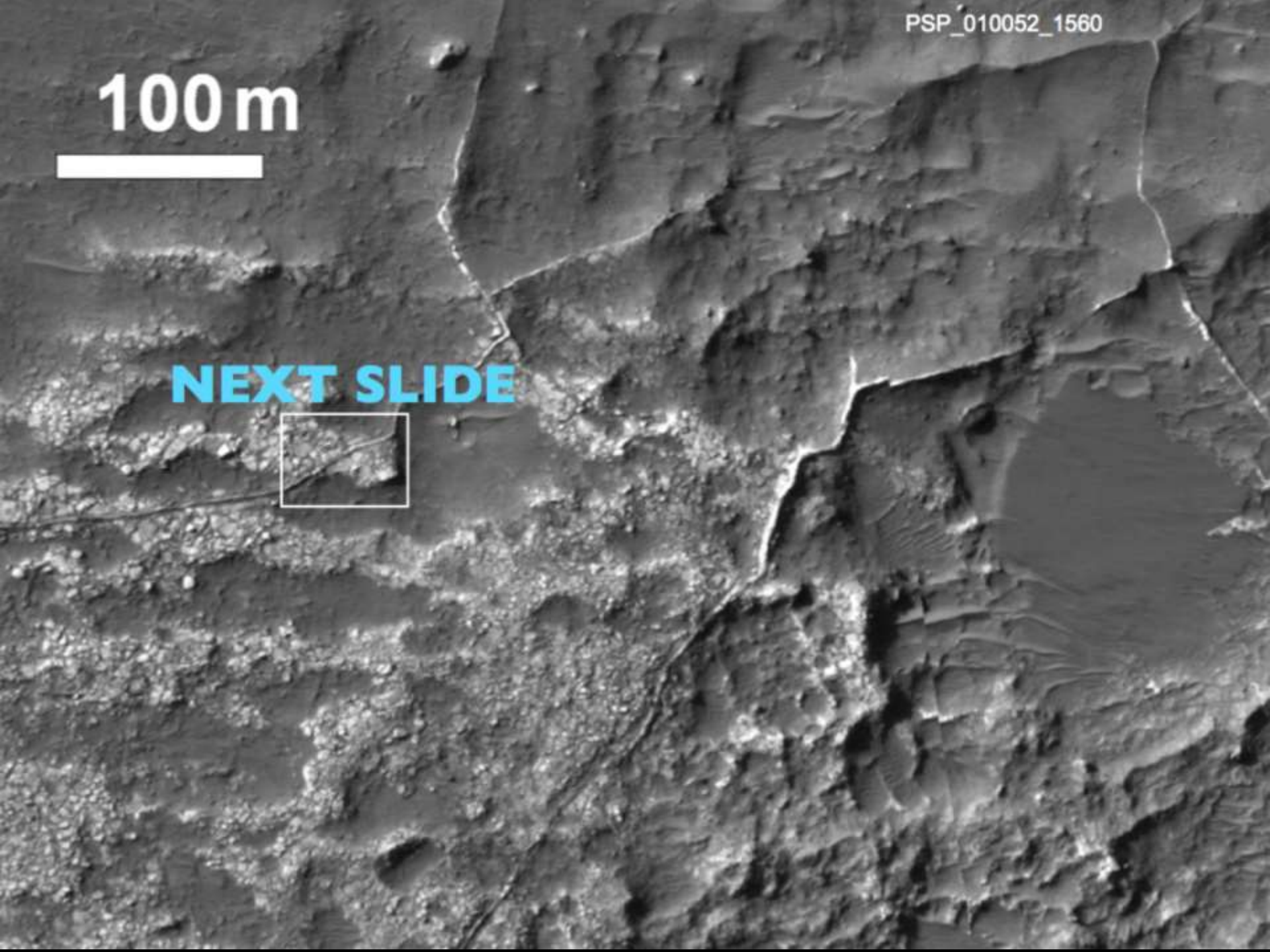
ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

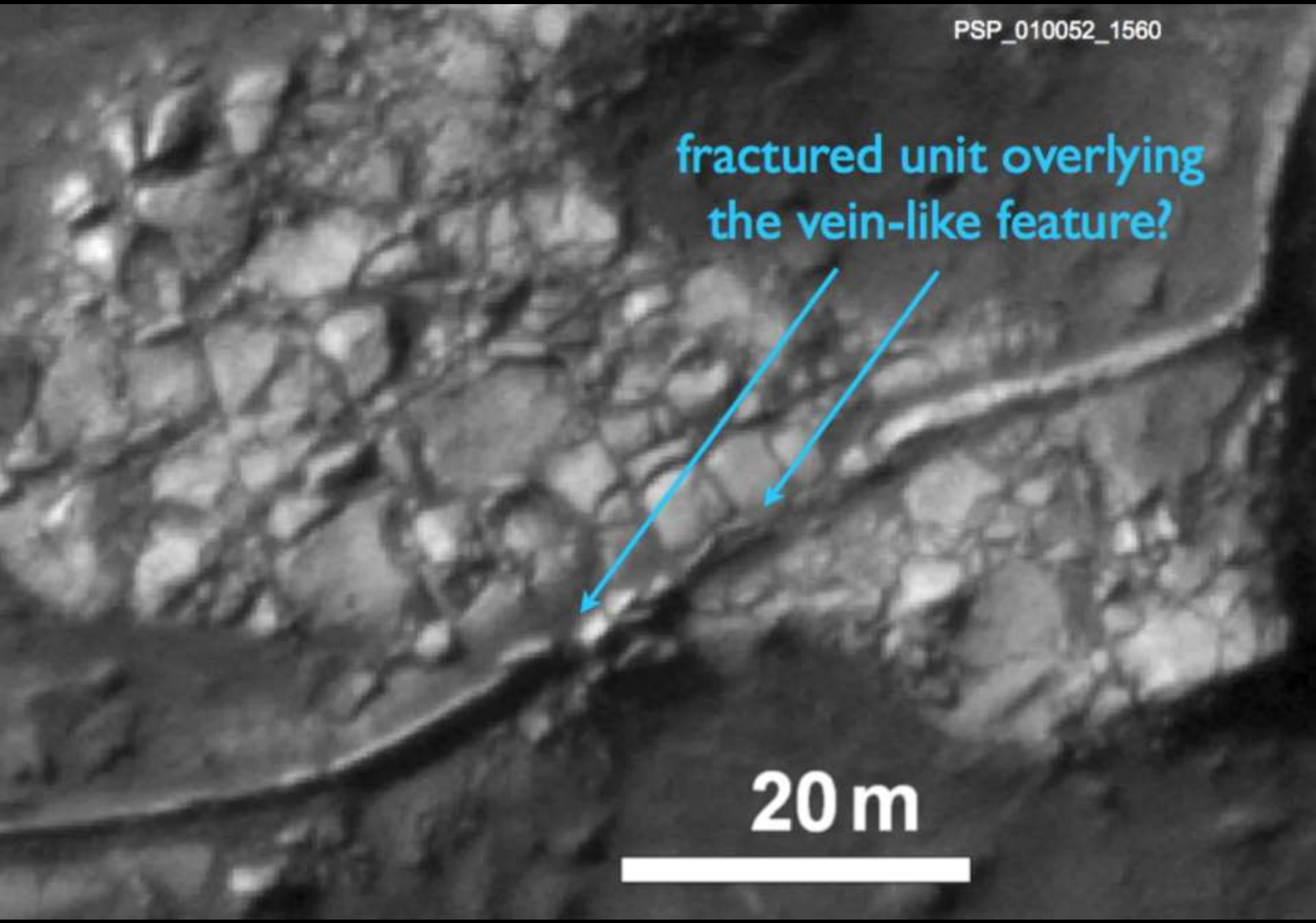

Bifurcating
channels
Pitted
Fractured
light-toned
~0.25 km

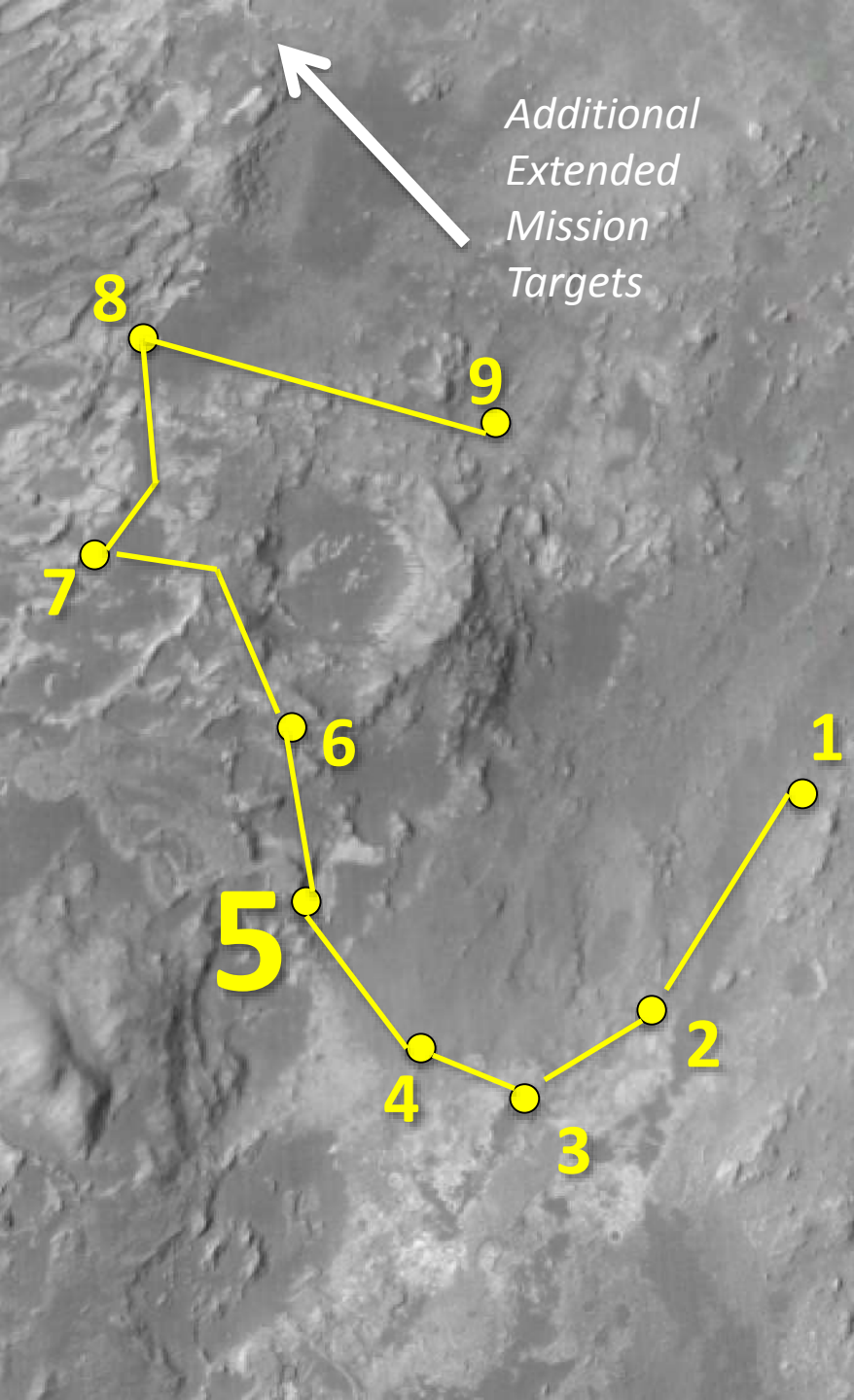

Pitted crater floor unit
100 m



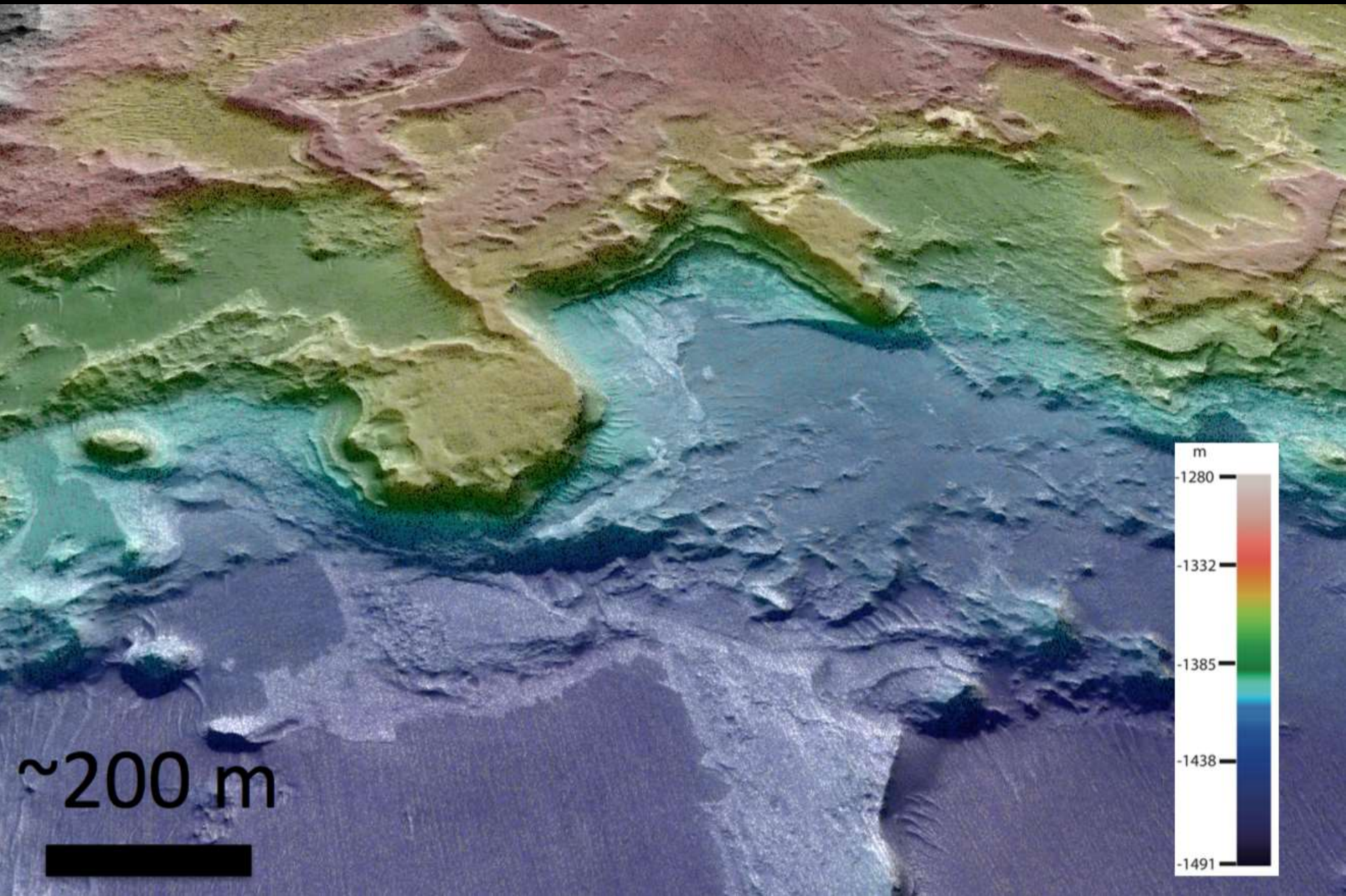
ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswadle delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km


PSP_010052_1560
100 m
NEXT SLIDE

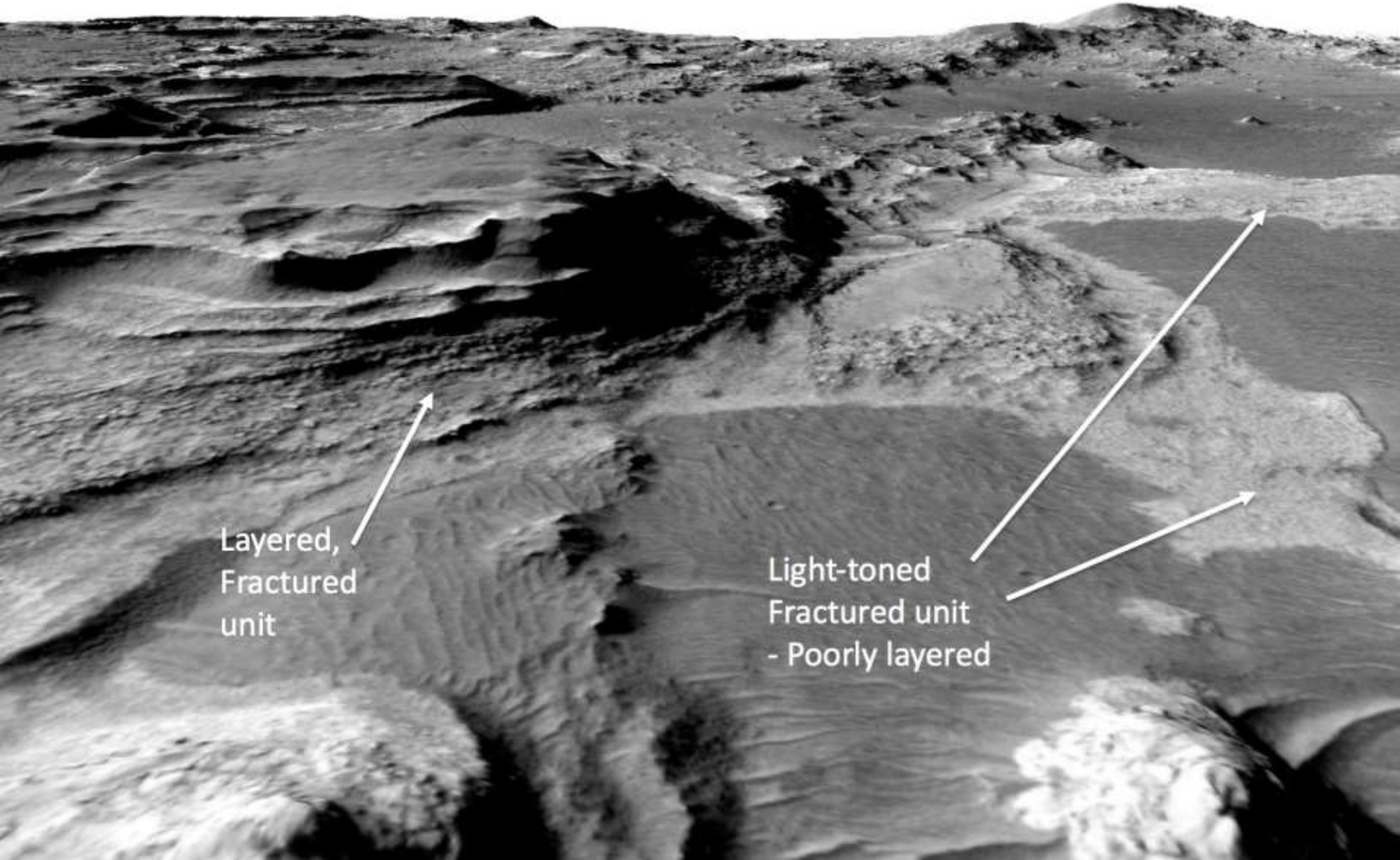

PSP_010052_1560
fractured unit overlying
the vein-like feature?
20 m

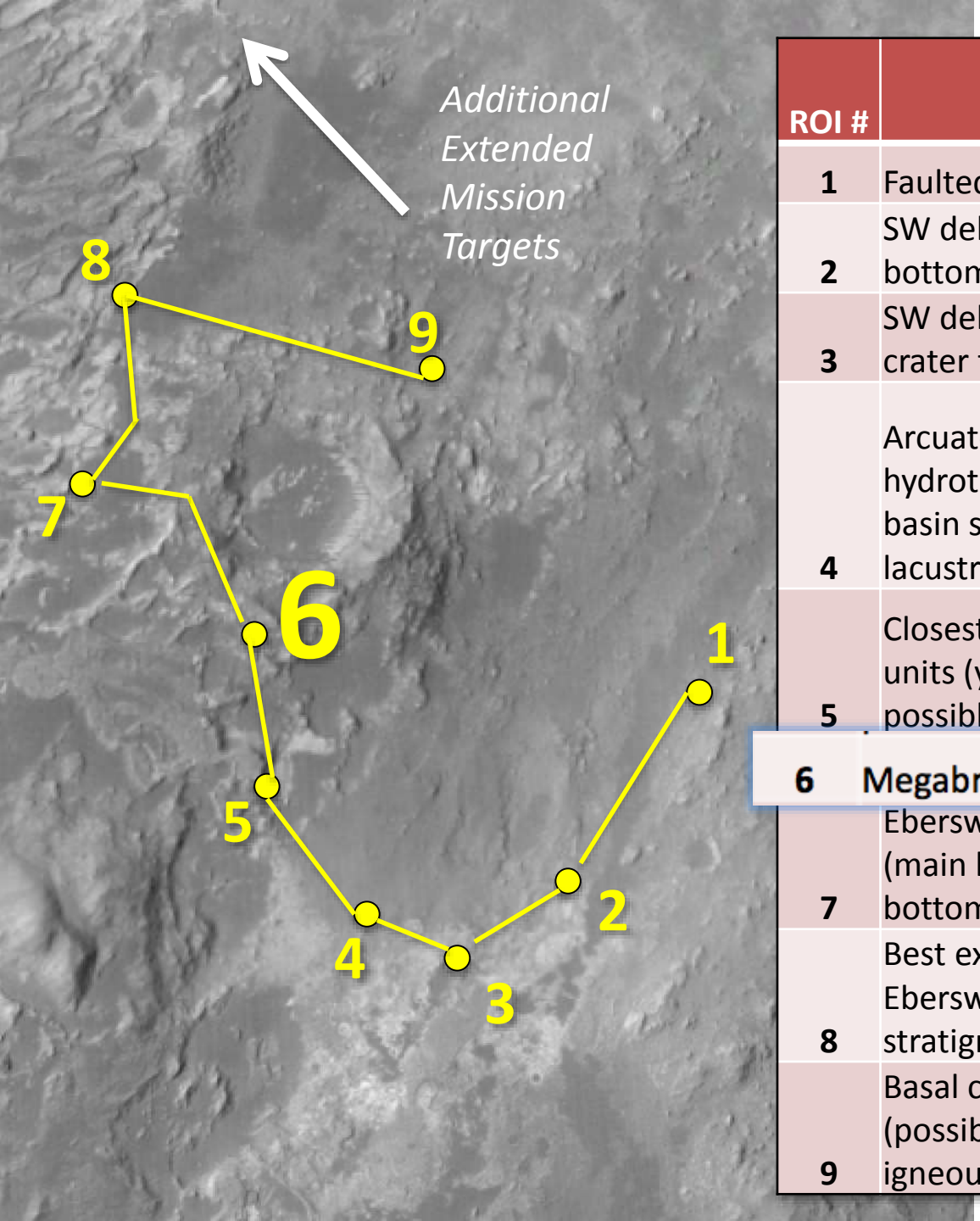


ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km


m
-1280
-1332
-1385
-1438
-1491
~200 m

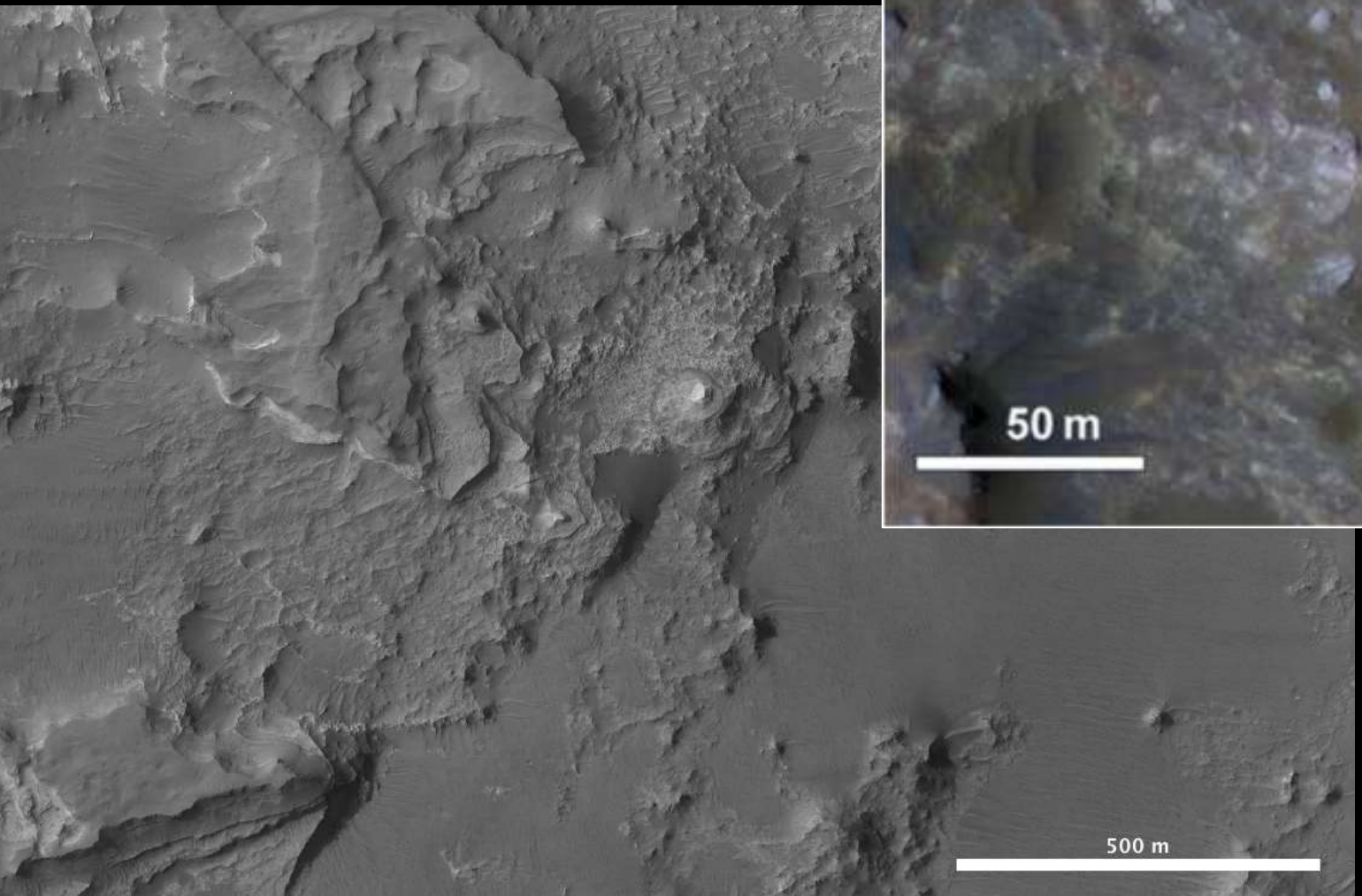
~40 m of delta stratigraphy exposed in cliff faces that are shedding boulders

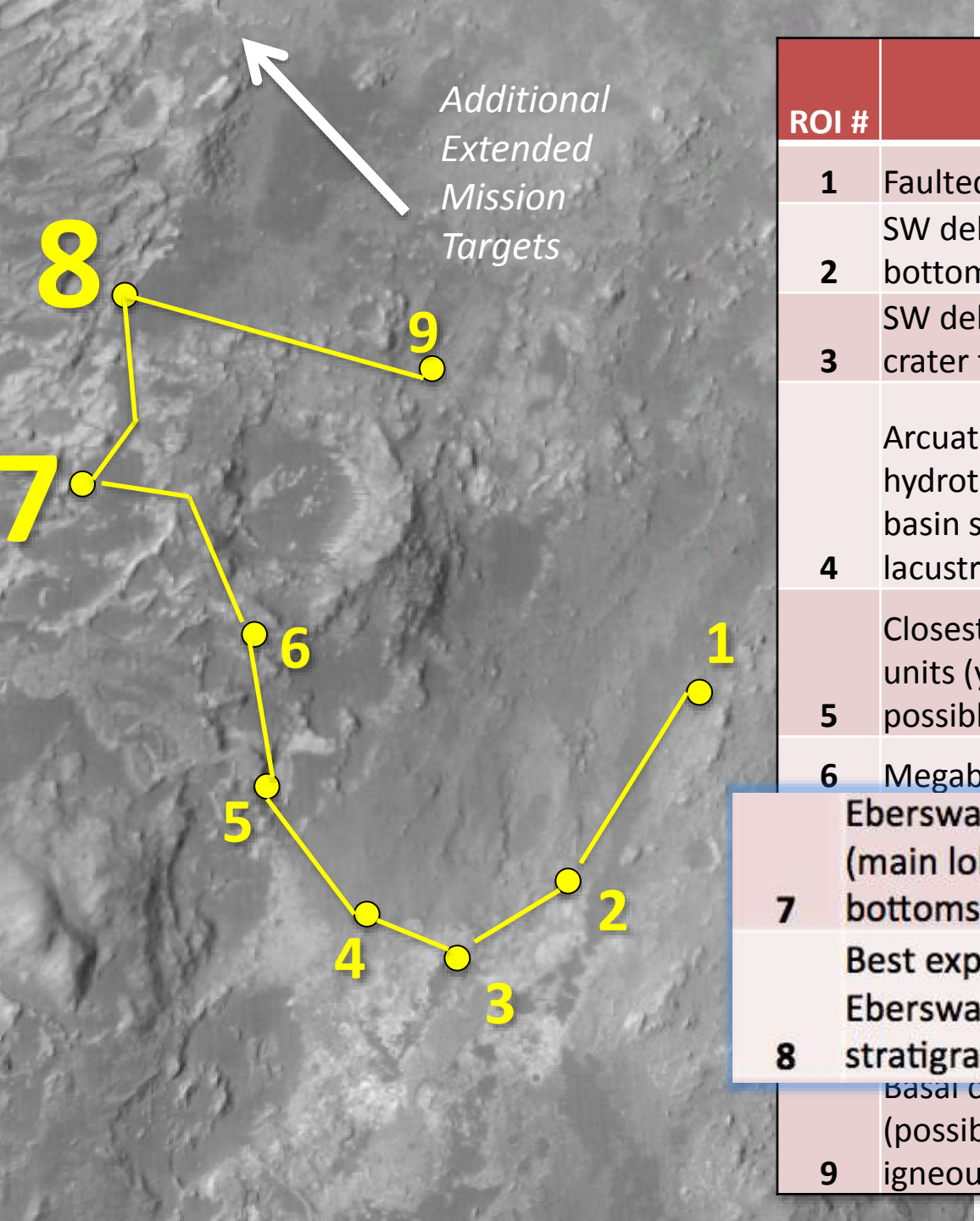




ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswalde delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

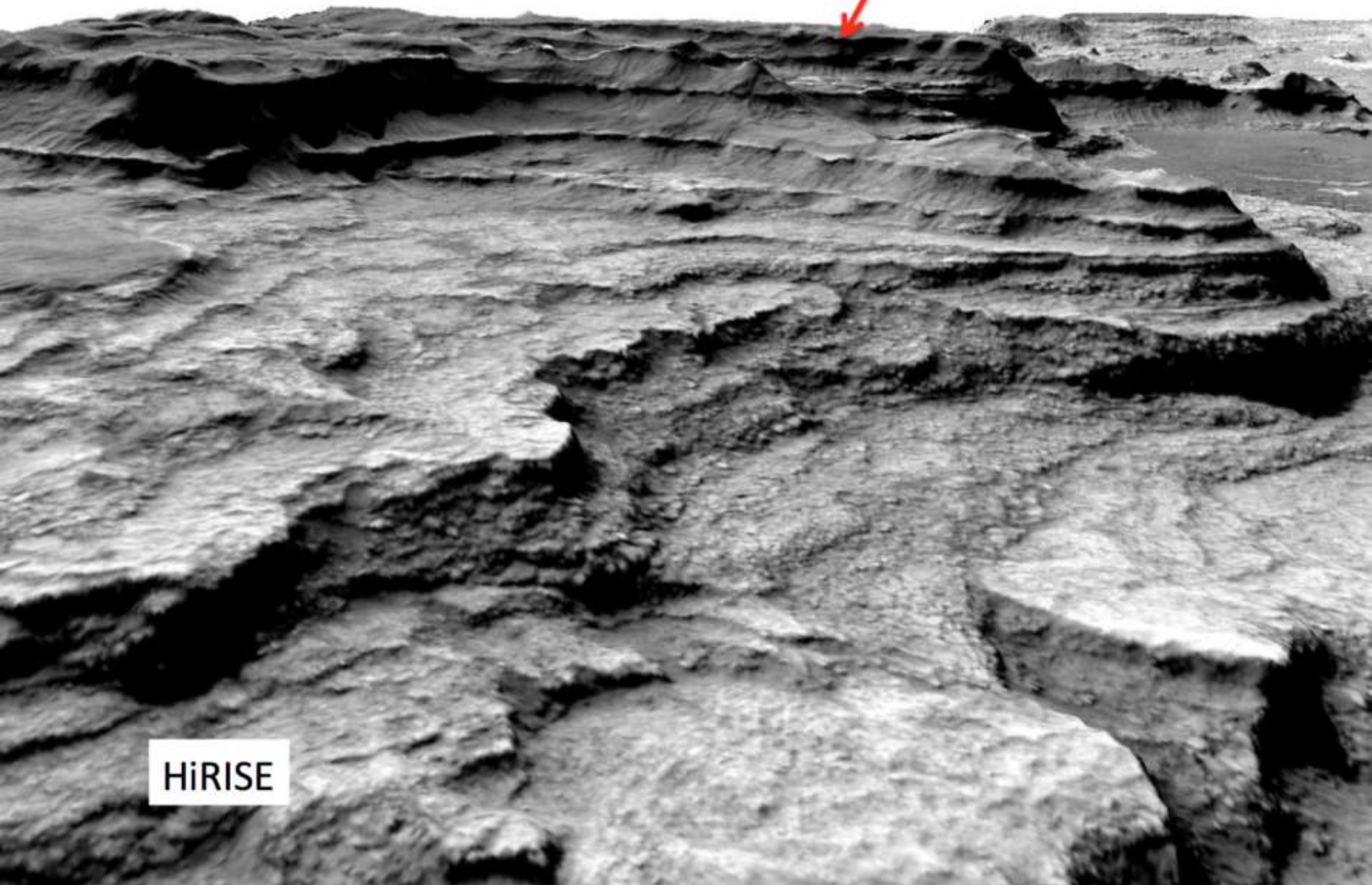
ROI: Delta sediments in contact with megabreccia

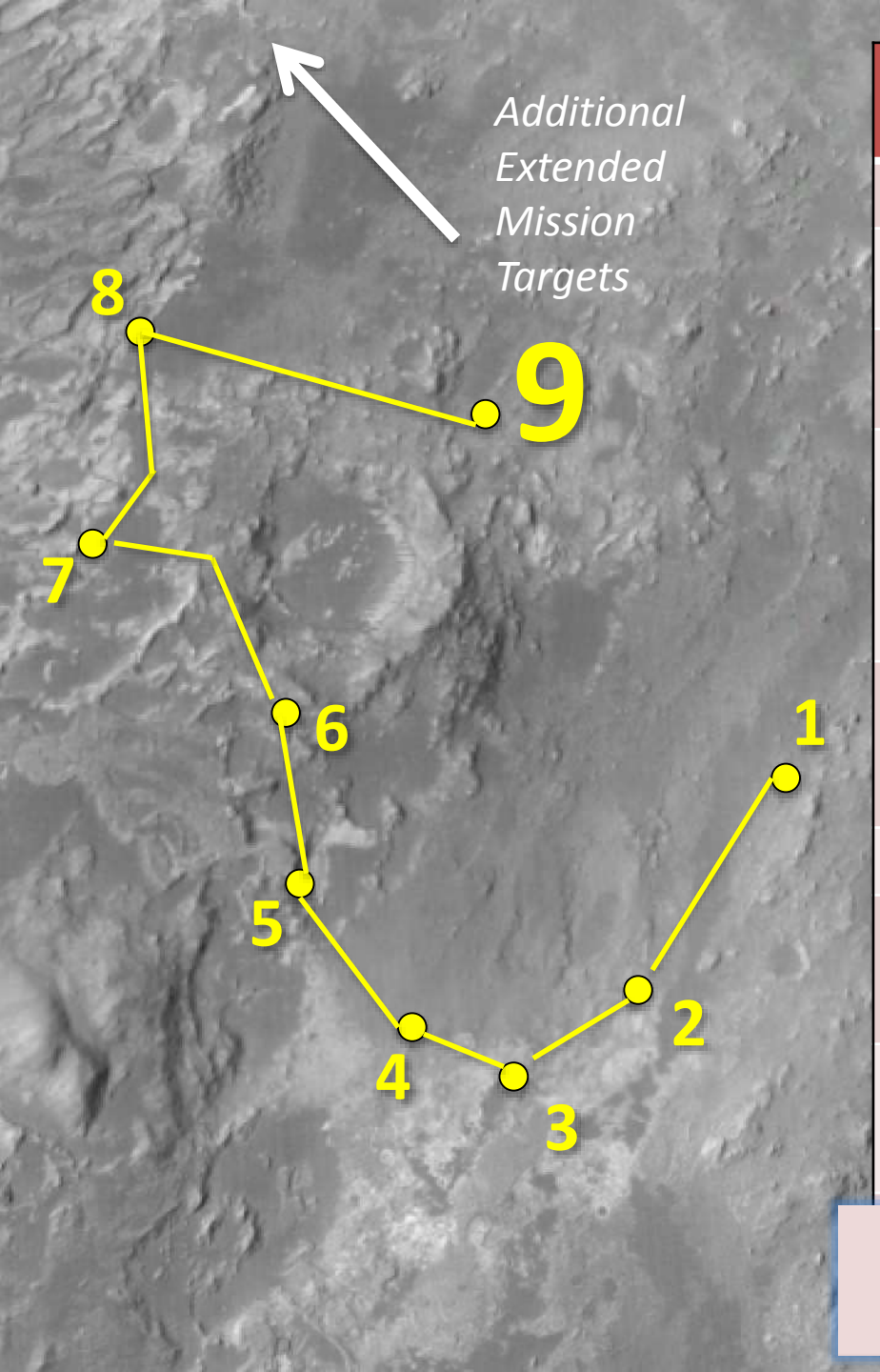




ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswadle delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

Extensive, layered delta sediments with good evidence for active erosion and recent exhumation

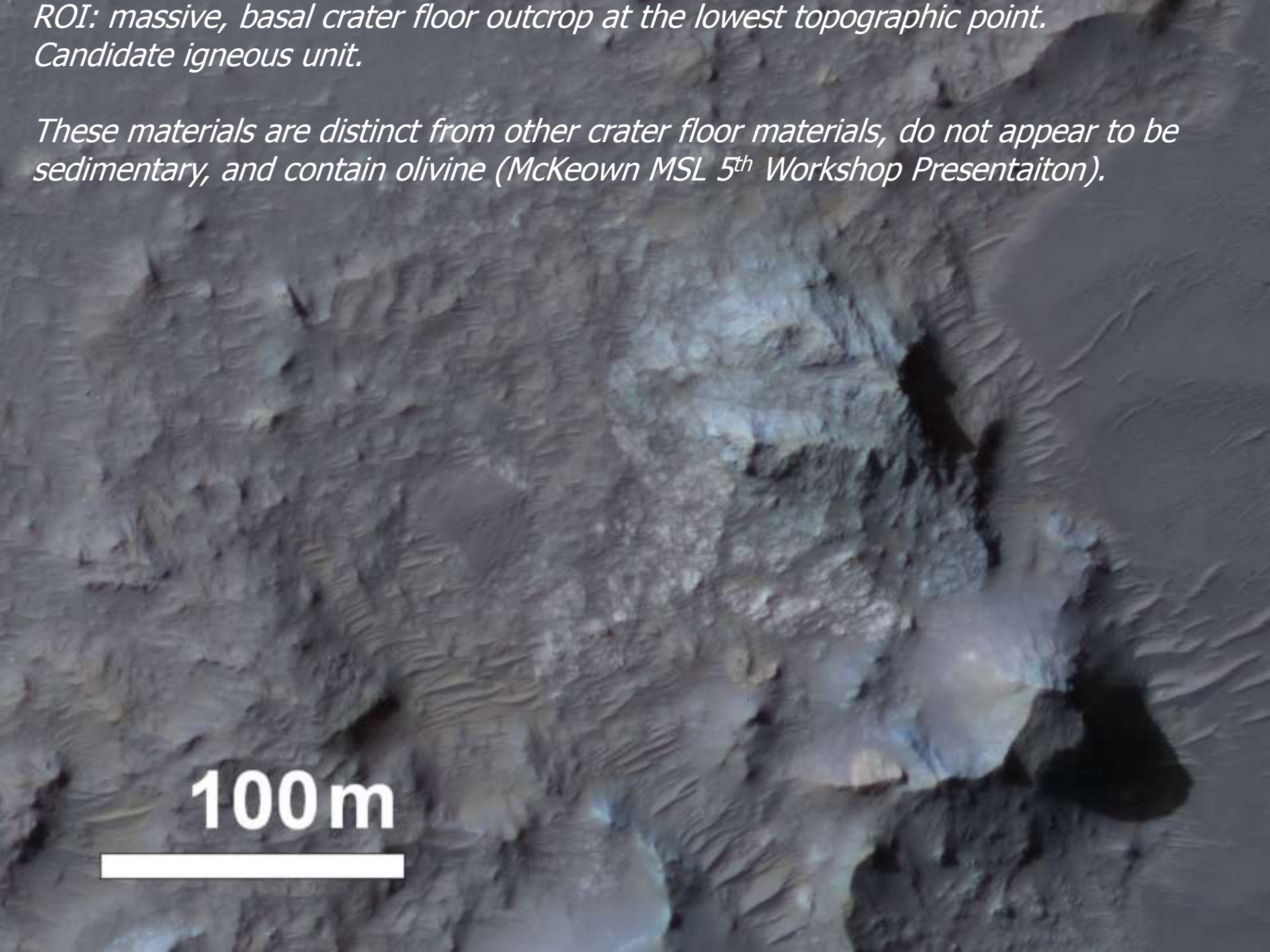


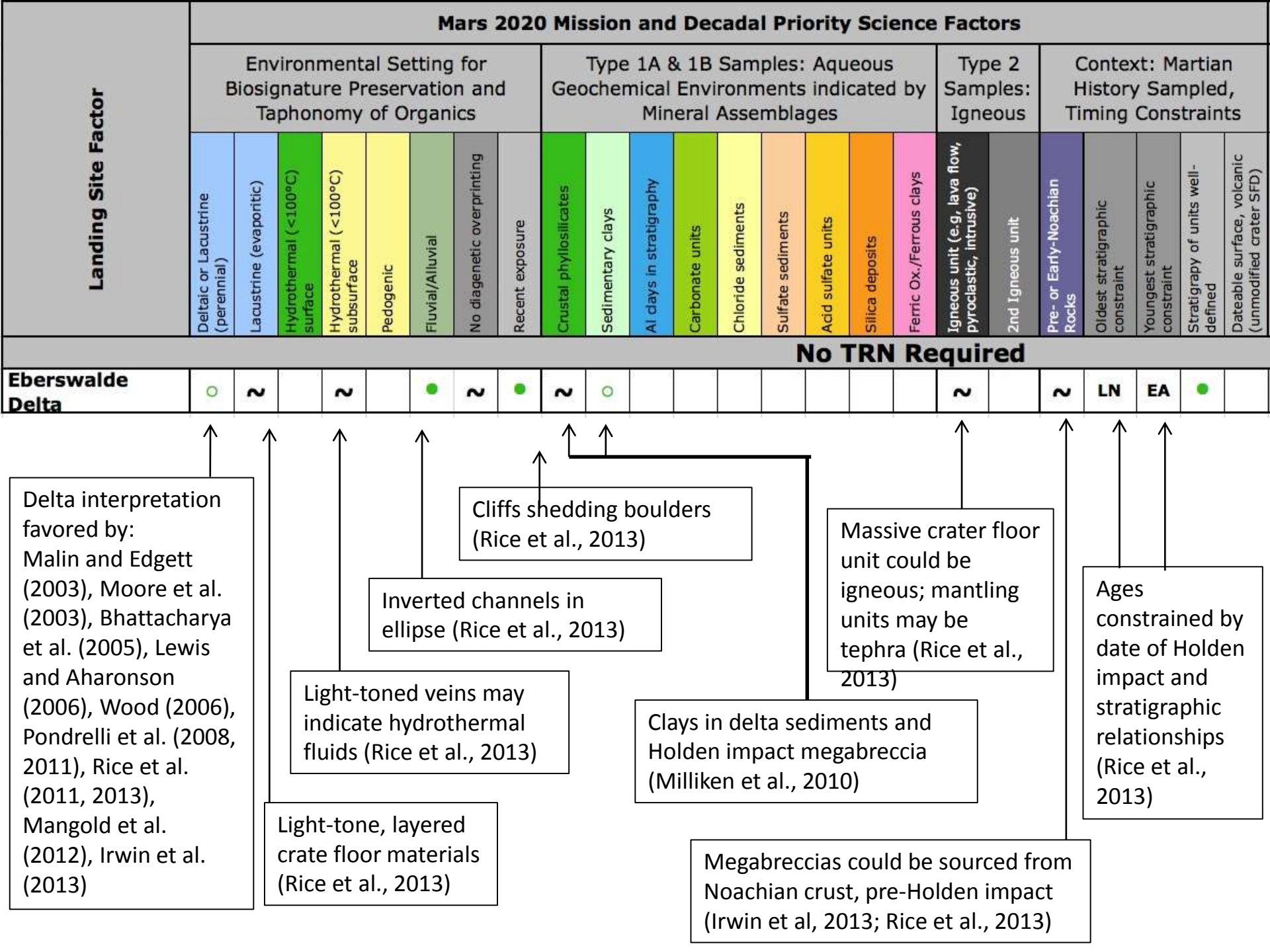


ROI #	Target(s)	Distance b/w ROIs	Total Distance
1	Faulted basin outcrop	0 km	0 km
2	SW delta units (possible bottomsets)	2.7 km	2.7 km
3	SW delta units; pitted crater floor unit	1.8 km	4.5 km
4	Arcuate veins (possibly hydrothermal); Fractured basin sediments (possibly lacustrine)	1.3 km	5.8 km
5	Closest Eberswalde delta units (youngest lobe, possible bottomsets)	2.1 km	7.9 km
6	Megabreccia; delta units	1.6 km	9.5 km
7	Eberswadle delta units (main lobe, possible bottomsets)	3.7 km	13.2 km
8	Best exposure of Eberswalde delta stratigraphy	2.0 km	15.2 km
9	Basal crater floor unit (possible impact melt or igneous unit)	4.3 km	19.5 km

ROI: massive, basal crater floor outcrop at the lowest topographic point. Candidate igneous unit.

These materials are distinct from other crater floor materials, do not appear to be sedimentary, and contain olivine (McKeown MSL 5th Workshop Presentaiton).




Mars 2020 Mission and Decadal Priority Science Factors
Landing Site Factor
Environmental Setting for Biosignature Preservation and Taphonomy of Organics
Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages
Type 2 Samples: Igneous
Context: Martian History Sampled, Timing Constraints
Deltaic or Lacustrine (perennial)
Lacustrine (evaporitic)
Hydrothermal (<100°C) surface
Hydrothermal (<100°C) subsurface
Pedogenic
Fluvial/Alluvial
No diagenetic overprinting
Recent exposure
Crustal phyllosilicates
Sedimentary clays
Al clays in stratigraphy
Carbonate units
Chloride sediments
Sulfate sediments
Acid sulfate units
Silica deposits
Ferric Ox./Ferrous clays
Igneous unit (e.g, lava flow, pyroclastic, intrusive)
2nd Igneous unit
Pre- or Early-Noachian Rocks
Oldest stratigraphic constraint
Youngest stratigraphic constraint
Stratigrapy of units well-defined
Dateable surface, volcanic (unmodified crater SFD)
No TRN Required
Eberswalde Delta
LN
EA
Delta interpretation favored by: Malin and Edgett (2003), Moore et al. (2003), Bhattacharya et al. (2005), Lewis and Aharonson (2006), Wood (2006), Pondrelli et al. (2008, 2011), Rice et al. (2011, 2013), Mangold et al. (2012), Irwin et al. (2013)
Light-tone, layered crate floor materials (Rice et al., 2013)
Light-toned veins may indicate hydrothermal fluids (Rice et al., 2013)
Inverted channels in ellipse (Rice et al., 2013)
Cliffs shedding boulders (Rice et al., 2013)
Clays in delta sediments and Holden impact megabreccia (Milliken et al., 2010)
Massive crater floor unit could be igneous; mantling units may be tephra (Rice et al., 2013)
Megabreccias could be sourced from Noachian crust, pre-Holden impact (Irwin et al, 2013; Rice et al., 2013)
Ages constrained by date of Holden impact and stratigraphic relationships (Rice et al., 2013)

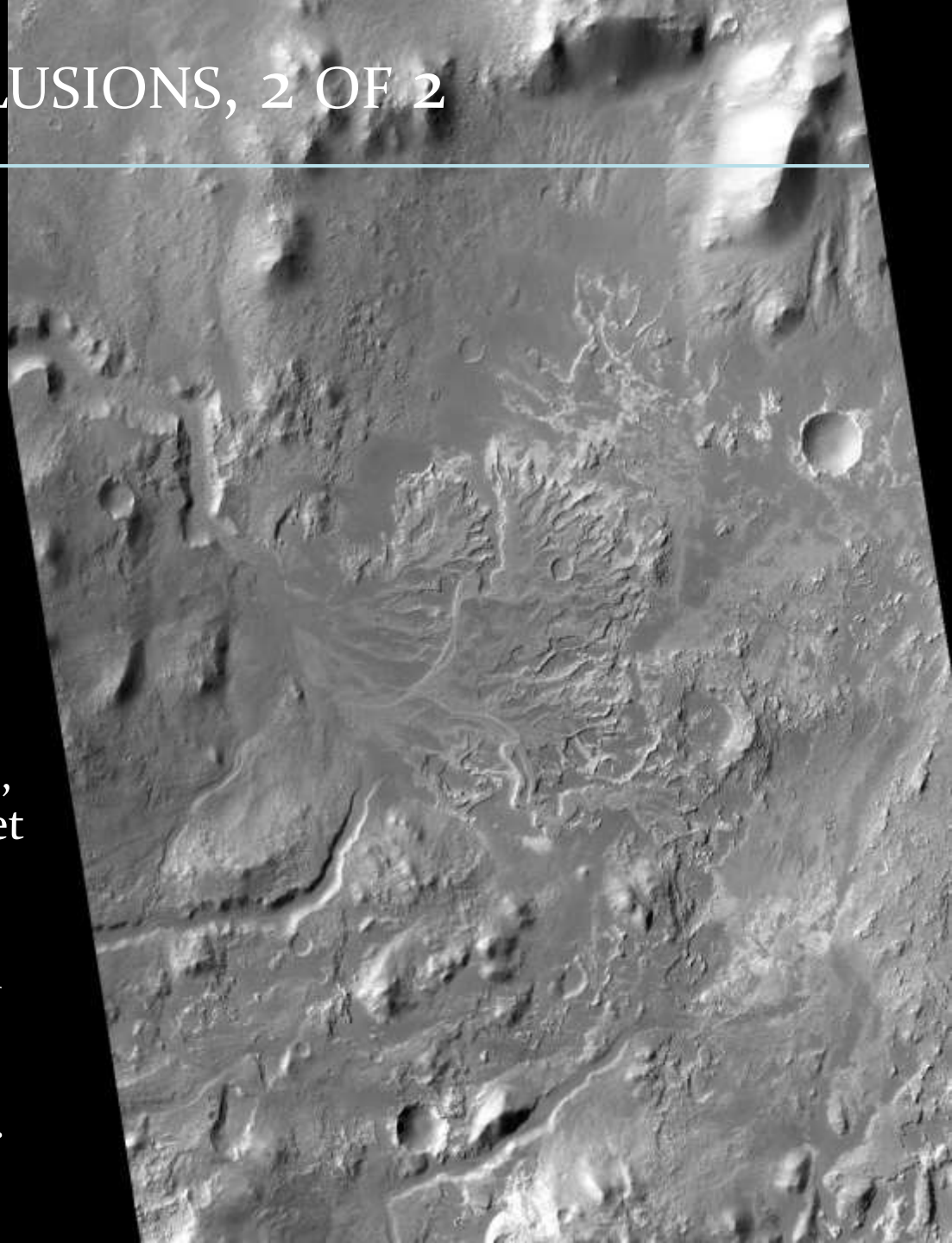
Backup Slides

Conclusions, 1 of 2

- Eberswalde postdates Holden basin (MN), predates Holden crater (H)
- Muting of relief continued after Holden impact
- Fresh craters formed on Holden rim & secondaries, later dissection
- Eberswalde delta northwest lobe formed first, then eastern lobes
- If it's an alluvial fan, then it's not due to the Holden impact
- Late transition from distributive to transportive planform
- Meandering possibly enabled by cementation
- Paleochannel width consistent with meander geometry
- Dominant discharge about 400 and 200 m^3/s in two late paleochannels
- Event runoff production up to 1 cm/day
- Annual runoff production (intermittent) about 1-20 cm/year
- Annual snowmelt or infrequent moderate rainfall are possible
- Deposition timescale 10^4-10^6 years for water/sed volume of 1,000 – 10,000
- Abundant outcrops in MSL ellipse, almost all under water

Conclusions, 2 of 2

- Very short deposition time scales are implausible
- Can concentrate, preserve, and exhume organics (if present)
- Diverse materials in Holden ejecta, but not in place
- Date the Holden impact?
- Site thoroughly mapped and vetted for MSL
- Low elevation provides margin
- REFS: Malin and Edgett (2003), Moore et al. (2003), Jerolmack et al. (2004), Bhattacharya et al. (2005), Lewis and Aharonson (2006), Wood (2006), Pondrelli et al. (2008, 2011), Rice et al. (2011, 2013), Mangold et al. (2012), papers by J. Grant and T. Parker



Why go to a deltaic site?

Deltas and perennial lakes may be the best environments for biotic production, concentration and preservation of organic materials

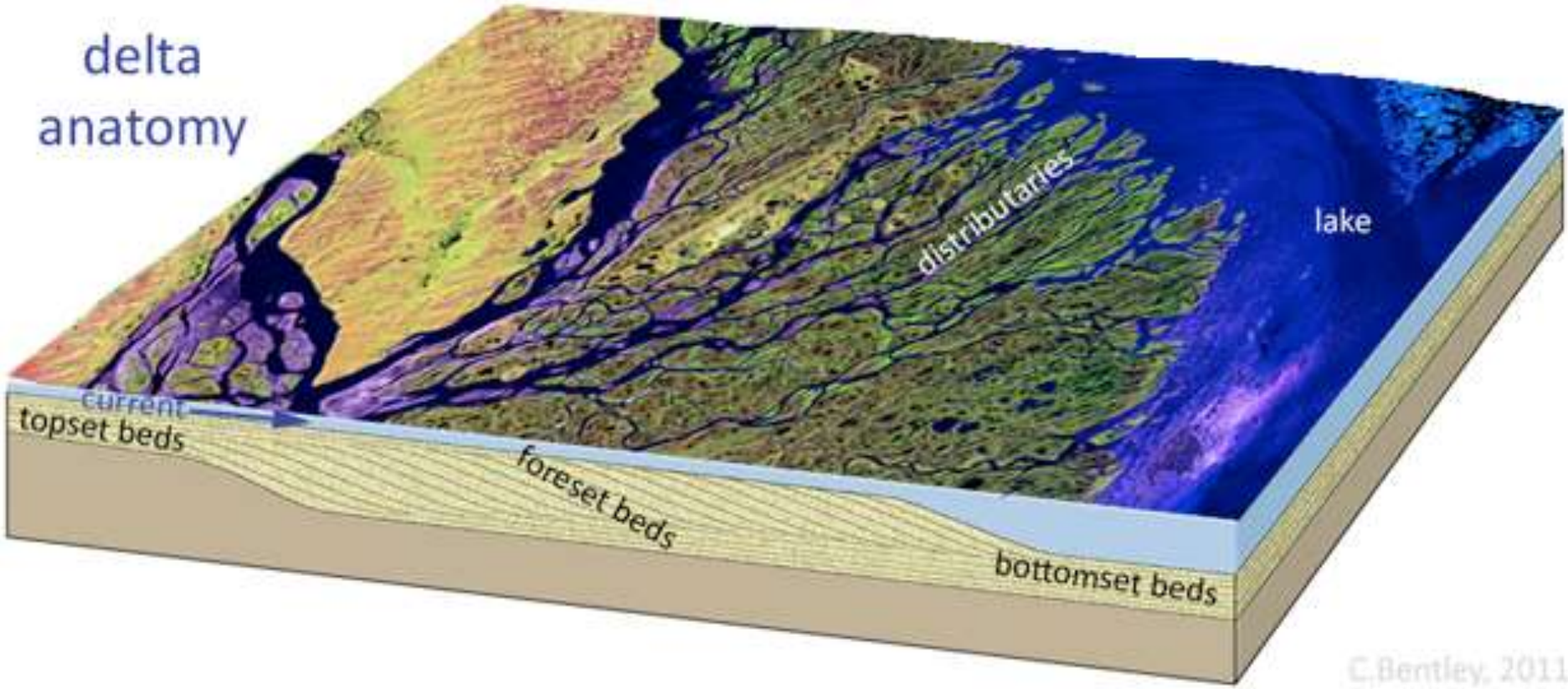
Martian context → early Mars environment	*Support biotic OM formation*	*Support for abiotic OM formation*	*Support OM concentration*	*Support preservation*
Eolian sediments (sand)	low	low	low	low
Altered eolinites (dust)	very low	low	low	low
Fluvial channel	low	low	low	low
Fluvial floodplain	low-mod	low	mod	mod
Alluvial fan	low	low	low	low
Deltaic	high	low	high	high
Lacustrine (perennial)	high	low	high	high
Lacustrine (evaporitic)(Cl)	low	low	high	high-very high
Lacustrine (evaporitic)(SO_4)	mod	low	high	high-very high
Regional groundwater pore system	low	low	low	low
Glacial deposits	low	low	low	low
Permafrost	low	low	low	mod
Soil (surface fines chemically altered by atmosphere)	low	low	low	low
Regolith/Fractured bedrock (not soil)	low	low	low	low

mod, moderate; n/a, not available.

Summons et al. (2011), Table 3

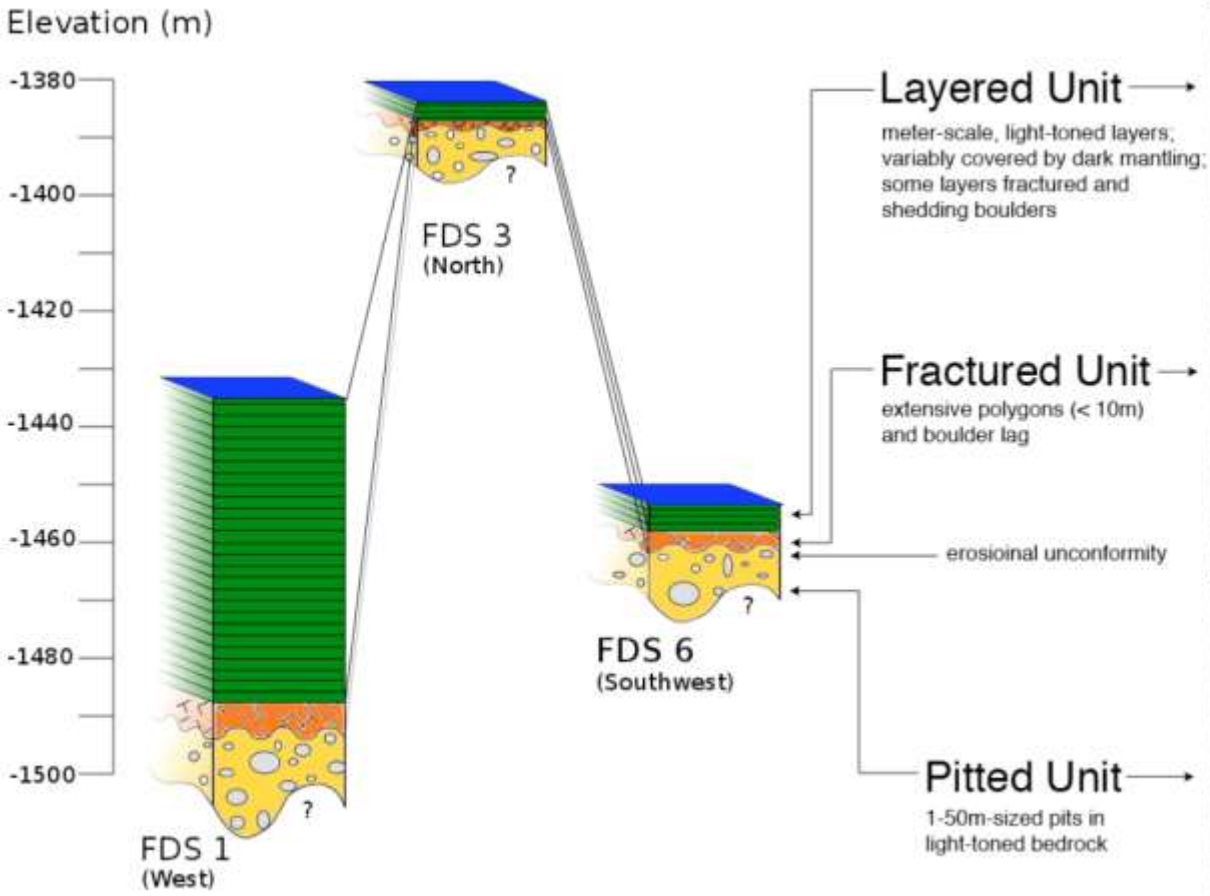
What makes deltaic-lacustrine systems good for biosignature formation and preservation?

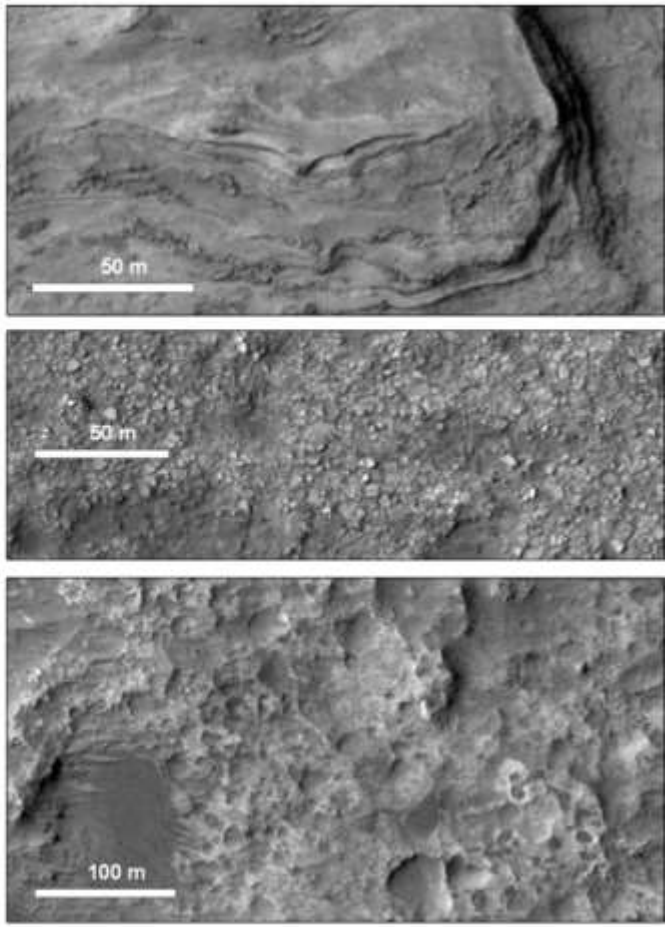
- Rapid deposition due to abrupt change in sediment transport efficiency => rapid burial => enhanced preservation of organics
- Enhanced settling of fines (silts & clays) from suspension
- Continuous input of mineral ‘resources’ – nutrients
- Low energy environments – reduced destruction by high energy fluid flows



The bottomset beds are created from the lightest suspended particles that settle farthest away from the active delta front, and this is where clays and organic matter are concentrated.

→ *This context is key! With a delta, we know exactly where our best chances of findings organics will be!*


Elevation (m)
-1380
-1400
-1420
-1440
-1460
-1480
-1500
FDS 3
(North)
FDS 6
(Southwest)
FDS 1
(West)
?
Layered Unit
meter-scale, light-toned layers; variably covered by dark mantling; some layers fractured and shedding boulders
Fractured Unit
extensive polygons (< 10m) and boulder lag
erosioinal unconformity
Pitted Unit
1-50m-sized pits in light-toned bedrock


50 m
50 m
100 m

Eberswalde Crater Paleohydrology

Eberswalde meander dimensions (m)

Paleo-channel	**Width (mean of 5)** W_b	**Wavelength** λ_m	**Arc distance (mean of 2)** λ_a	**Belt width** B	**Radius of curvature (mean of 3)** R_c
North	130	1240	1140	1000	260
South	50	740	530	420	170

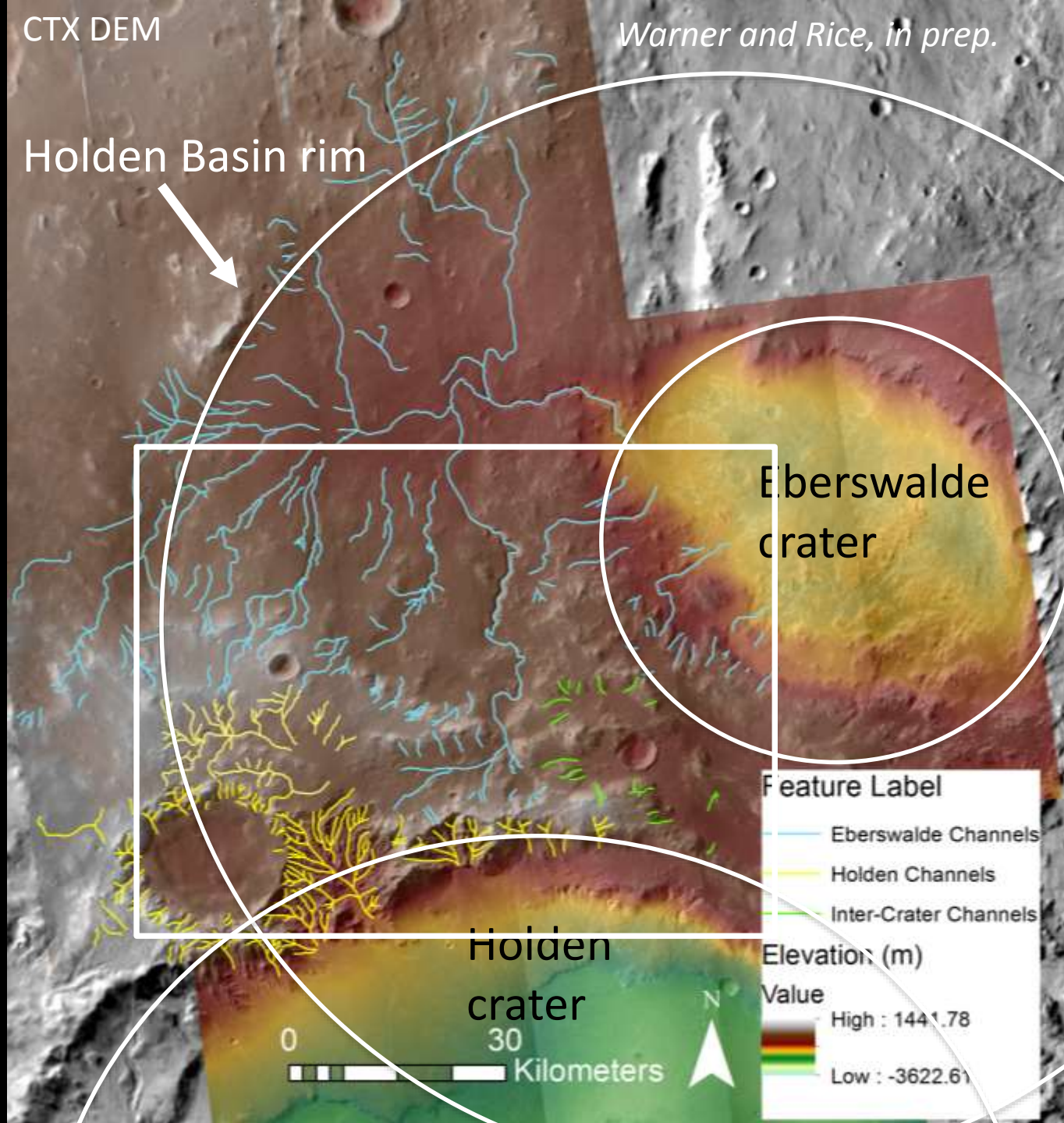
Measured and expected channel width based on meander dimensions (m)

Paleo-channel	**Measured width (mean of 5)**	**Width, from wavelength**	**Width, from arc distance**	**Width, from belt width**	**Width, from radius of curvature**
North	130	100	120	130	100
South	50	60	60	60	70

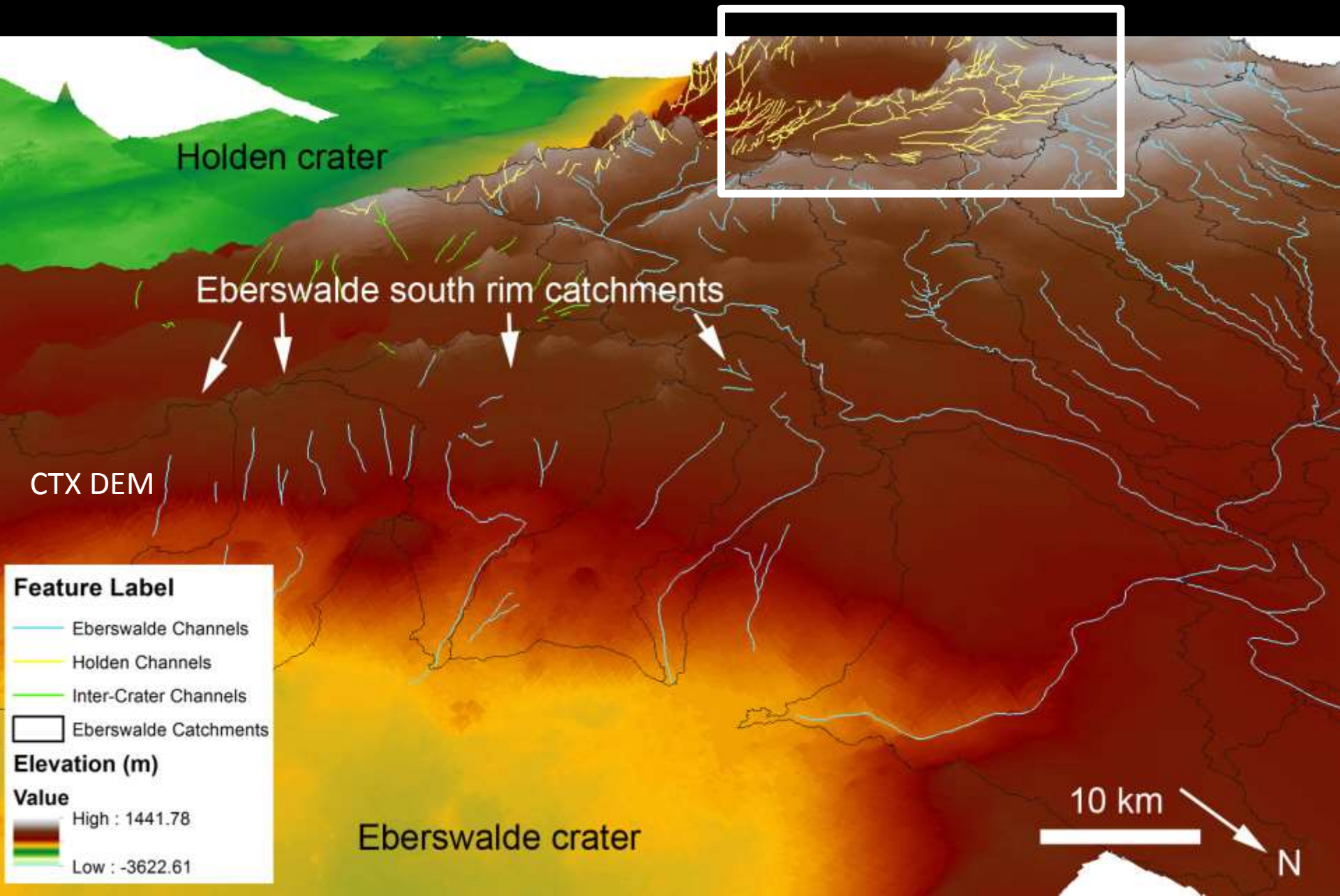
$W_b = 0.17\lambda_m^{0.89}$ $W_b = 0.23\lambda_a^{0.89}$ $W_b = 0.27B^{0.89}$ $W_b = 0.71R_c^{0.89}$ (*Williams*, 1986)

Valley Networks: Precipitation

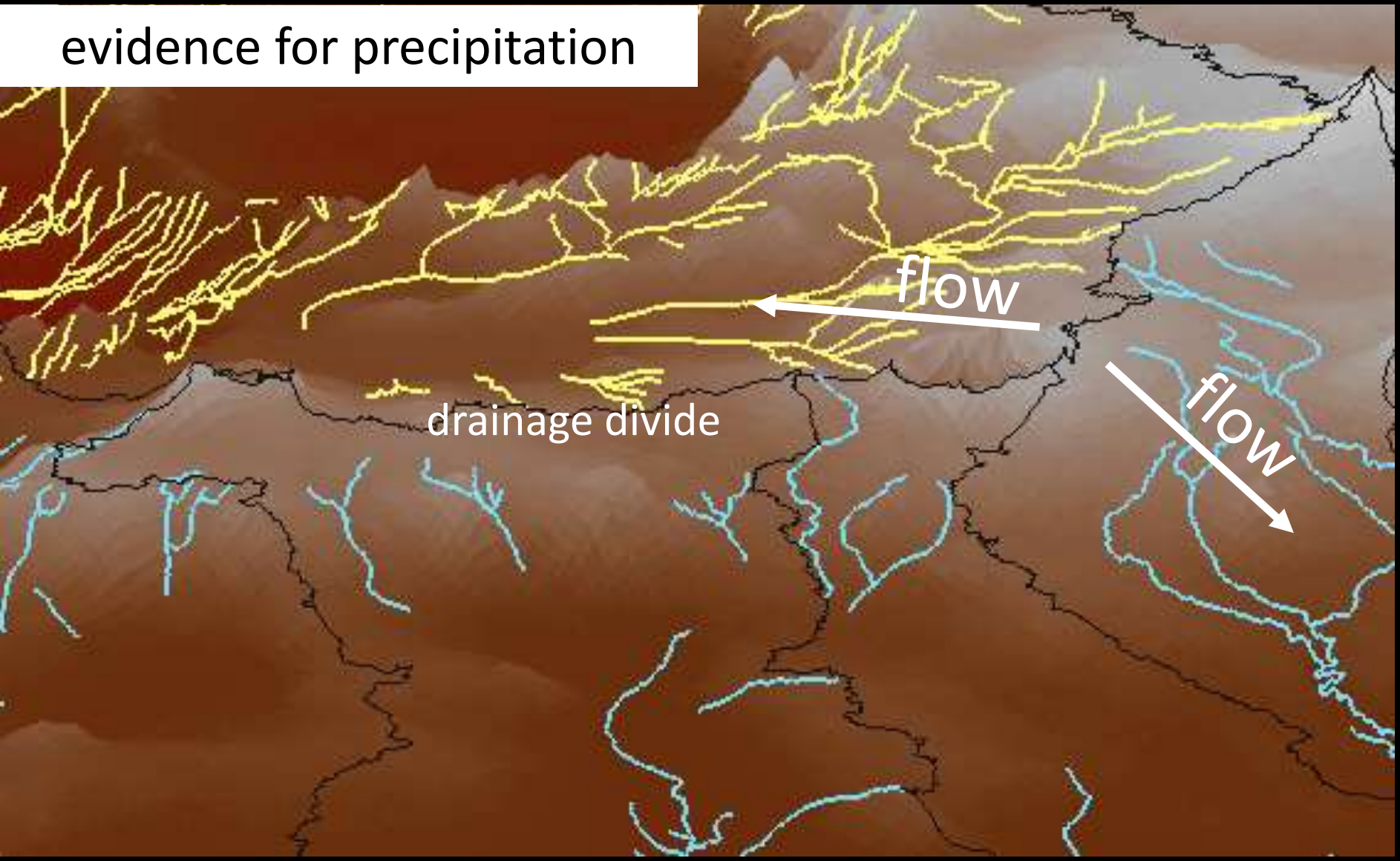
- Without plate tectonics topography on Mars is created by impact cratering.
- Craters provide elevated terrains (rims) and depositional basins (floors).
- Dendritic networks that emerge from the crests of elevated highlands may indicate precipitation.



Crater Rims form Drainage Catchments

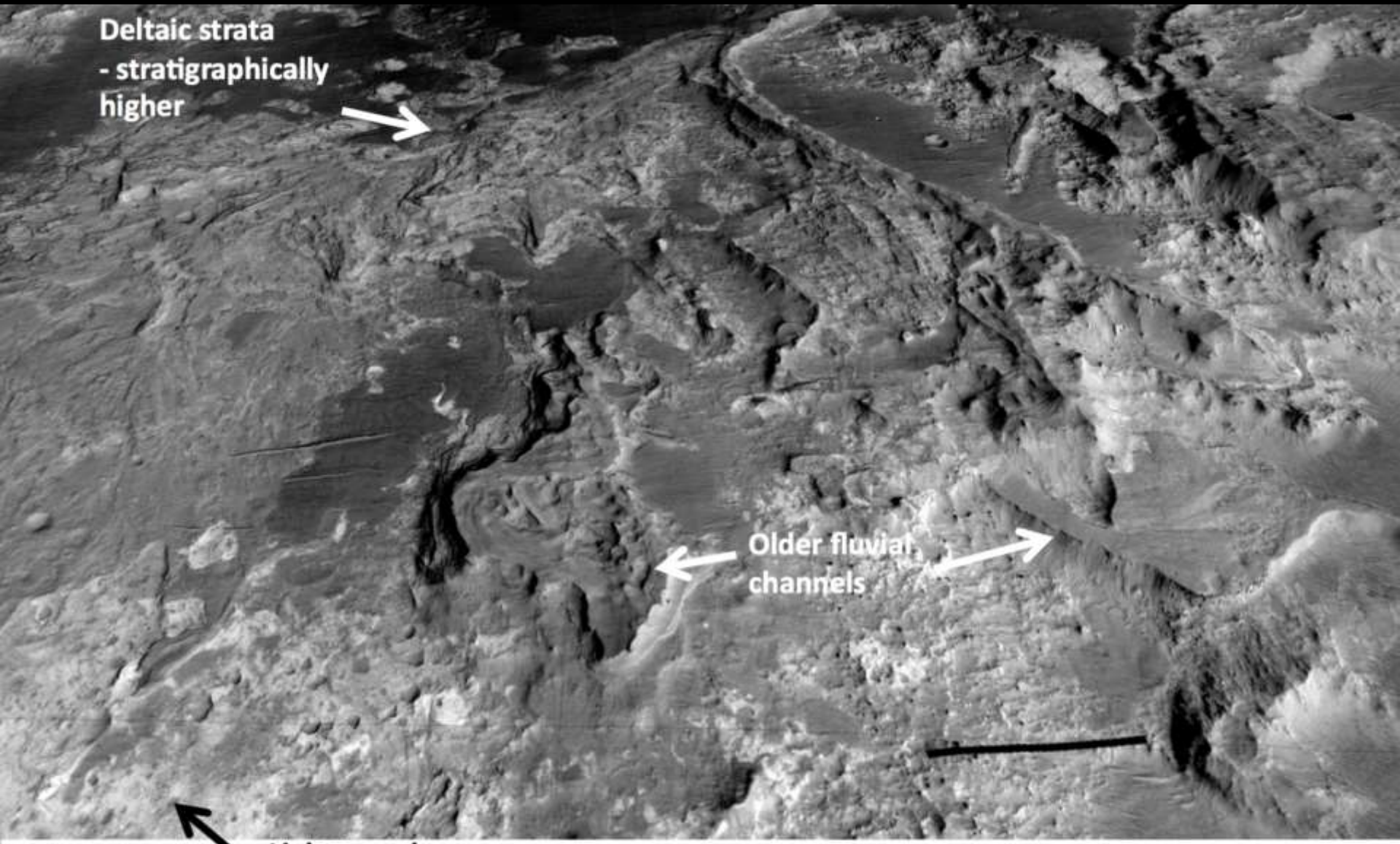


Valley Networks – Drainage Divides



CTX DEM

Warner and Rice, in prep.


Deltaic strata
- stratigraphically
higher
Older fluvial
channels
Light toned
fractured unit

Backstepping delta?